AD 740825







MTI ... research and development division

194

Unclassified

Security Classification

| DOCUMENT CONTROL DATA - R & D | | |
|---|---|---|
| *(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)* | | |
| 1. ORIGINATING ACTIVITY *(Corporate author)* Mechanical Technology Incorporated<br>968 Albany-Shaker Road<br>Latham, New York 12110 | 2a. REPORT SECURITY CLASSIFICATION Unclassified | 2b. GROUP N/A |
| 3. REPORT TITLE Application of New and Improved Solid Lubricant Materials and Processes to Naval Aircraft | | |
| 4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)* Technical Report | | |
| 5. AUTHOR(S) *(First name, middle initial, last name)* M. B. Peterson<br>E. F. Finkin | | |
| 6. REPORT DATE July 14, 1971 | 7a. TOTAL NO. OF PAGES 139 | 7b. NO. OF REFS 41 |
| 8a. CONTRACT OR GRANT NO N62269-71C-0177<br>b. PROJECT NO.<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S) 71TR48<br>9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* None | |
| 10. DISTRIBUTION STATEMENT This document has been approved for public release and sale; its distribution is unlimited. | | |
| 11. SUPPLEMENTARY NOTES None | 12. SPONSORING MILITARY ACTIVITY Aero Materials Department<br>Naval Air Development Center<br>Warminster, Pennsylvania | |

13. ABSTRACT


The overall objective of the program was to help to extend the aircraft operating interval between rework and maintenance actions and savings of aircraft rework hours. The program goal was to improve the performance of current solid lubricant materials and processes, via several ways:

- Substitution of new and improved materials and processes
- Introduction of solid lubricants to new applications where they could be advantageously used
- Simplification or elimination of unneeded processing steps

A survey was made of the literature followed by visits to vendors to ascertain what new technology exists which would be applicable to naval aircraft. Visits were made to all seven Naval Air Rework Facilities during which time problems were identified and discussed; discussions were also held with vendors. Comparison visits were made to other service installations. Formal recommendations were formulated and are contained in this report.


DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Unclassified

Security Classification

Unclassified
Security Classification

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Rework, maintenance, lubrication, lubricants, wear, landing gear, airframe, wings, hydraulic cylinders, seals, brakes, bushings, bearings, valves, materials, bonded films, greases, processing, quality assurance, aircraft. | | | | | | |

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Unclassified
Security Classification

MTI 71TR48

Analytical Rework Program

# APPLICATION OF NEW AND IMPROVED SOLID LUBRICANT MATERIALS AND PROCESSES TO NAVAL AIRCRAFT

Emphasizing Reduced Maintenance and Improved Reliability

M. B. Peterson and E. F. Finkin

July 14, 1971





MECHANICAL TECHNOLOGY INCORPORATED
968 Albany-Shaker Road
Latham, New York 12110

MTI 71TR48

FINAL REPORT

Analytical Rework Program

# APPLICATION OF NEW AND IMPROVED SOLID LUBRICANT MATERIALS AND PROCESSES TO NAVAL AIRCRAFT

Emphasizing Reduced Maintenance
and Improved Reliability

Prepared For

Aero Materials Department
Naval Air Development Center
Warminster, Pennsylvania

Prepared Under

Contract No. N62269-71C-0177

Prepared By

M. B. Peterson

and

E. F. Finkin

July 14, 1971

MECHANICAL TECHNOLOGY INCORPORATED

968 Albany-Shaker Road, Latham, New York 12110 Telephone (518)785-2320

## TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

## ACKNOWLEDGEMENT

This program was established by Naval Air Systems Command, Code AIR-4117, as part of the Analytical Rework Program under Air Task WR-1-5060, "Application of New and Improved Materials and Processes" being conducted by the Naval Air Development Center.

The authors would like to acknowledge the many contributions that others have made to this program. Mr. A. J. Koury (Code AIR-4117) who instigated the study and made many helpful suggestions. M. J. Devine who contributed technical direction and continuously monitored the program. Mrs. Maj-Britt Leish who visited the Naval Air Rework Facilities with the authors and was an active participant during the whole program. In addition, the following materials engineers at the NARFS made many contributions in time and in substance to the successful completion of the project.

Naval Air Rework Facility - Personnel

| | | |
|---|---|---|
| North Island | - | Len Meserole |
| Alameda | - | Robert Zilligen |
| Jacksonville | - | Ralph Wheat |
| Cherry Point | - | Fred Latham, John Majeski |
| Pensacola | - | Otis Hays |
| Quonset Point | - | M.J. Clifford, E. Charves |
| Norfolk | - | Joe Hendrich |

Many of the recommendations in this report were first made by the above mentioned people.

In addition, the authors wish to acknowledge the assistance and the courtesy extended by the Army, Rock Island Arsenal (Rock Island, Illinois) and ARADMAC (Corpus Christi, Texas) and by the Air Force, Warner Robins Air Materiel Area (Robins Air Force Base, Georgia), and by Mr. Pat Hampton at the latter.

## I. INTRODUCTION

Significant advances in the utilization of solid lubricants have occurred in the past twenty years. What was considered a technical curiosity a few years ago has now grown into a practical, expanding product area. It is quite understandable that many of these developments have not found their way into practice. Recognizing this, the Naval Air Systems Command (Code AIR-4117), under its Analytical Rework Program, initiated a study with Mechanical Technology Incorporated under Contract No. N62269-71-C-0177 entitled "Application of New and Improved Solid Lubricating Materials and Process to Naval Aircraft" to review their use. This program was a phase of AIR TASK WR-1-5060 "Application of New and Improved Materials and Processes" being conducted by the Naval Air Development Center.

The overall objective of this program was to improve the performance of current solid lubricant materials and processes so that the operating time between maintenance can be extended and maintenance hours can be saved. There are several ways in which this objective can be accomplished.

- Substitution of new materials, processes or designs which give longer lives
- Introduction of solid lubricant materials where they are not presently used and could be used effectively
- Simplification or elimination of un-needed processing steps

To help to accomplish this objective, a survey was first made of the literature followed by visits to vendors to ascertain what new technology exists which would be applicable to naval aircraft. This was done both from a research and development and from an application point of view. A review was also made of the aircraft manuals to determine where solid lubricants were used or to find applications where there is a short maintenance interval which solid lubricants could extend. Letters were then written to all solid lubricant manufacturers requesting product literature. In certain instances visits were made to discuss new applications or procedures for solid lubrication.

Visits were then made to all the Naval Air Rework Facilities (NARF). At each NARF, the following procedures were followed:

- A discussion was held with the materials division personnel to determine the lubricants used and any special problems which had arisen with their use.
- A collection was made of the local process specification and local engineering specifications which referred to the use of solid lubricants.
- The solid lubricant processing facility was visited and the application of the solid lubricant film was observed. The foremen were asked what films they applied, how they were applied, and to what parts they were applied.
- The various rework shops were visited and the shop foreman was asked two questions: are solid lubricants adequately performing their function in service and what parts of the aircraft currently require a large amount of rework or part replacement due to wear or galling?
- Discussions were held with engineering on the specific problems observed during the NARF visit.

After the NARF visit the aircraft manuals pertaining to the aircraft under study were reviewed to ascertain the specific details of rework such as part numbers, materials, lubricant procedures, and design. In certain instances, the supply system was checked for parts usage and which facilities used the parts.

Where conditions warranted the aircraft manufacturer was contacted for details. Discussions were also held with various vendors of solid lubricants, wear resistant treatments and component manufacturers on specific problems identified in the NARF visits.

For comparison purposes, visits were also made to two Army installations (ARADMAC, Corpus Christi, Texas; Rock Island Arsenal, Rock Island, Illinois),

and to an Air Force Installation (Robins AFB, Georgia). The personnel of these installations were extremely helpful and cooperative.

Based on these efforts, certain recommendations have been formulated concerning the application and use of solid lubricants in naval aircraft and supporting Research and Development efforts. These were forwarded to the Naval Air Systems Command for review, and updated versions of these recommendations are in the Appendix of this report.

This report is a summary of the work which was accomplished under this contract. The first two sections review some of the new applications and technology which exhibit significant potential for application to naval aircraft. These sections are not intended to be a review of the literature, but only list certain developments which are new or significant enough to contribute to the objective of the program. The remainder of the sections discuss the specific findings of the program. For the most part, the results are intended to be general; that is, to refer to the rework of naval aircraft rather than to the actions or procedures at specific Naval Air Rework Facilities. The formal recommendations are listed in the final section.

## II. NEW APPLICATIONS FOR SOLID LUBRICANTS

The earliest recorded uses of solids as lubricants was several hundred years ago and one of the first U.S. Patents appeared in 1927 (1). The first uses of solid lubricants, either organic or inorganic, was for metal working operations where both high temperatures and high loads combined to make lubrication difficult. Modern interest in the subject began with a 1941 publication concerning lubrication of bearings in vacuum x-ray tubes (2). The development of the aircraft gas turbine engine with its high temperatures gave a large impetus to this field and a series of technical investigations of the subject began. About the time that this work reached a peak in the late 50's the space program combined with higher performance military aircraft began. Here the demand for improved solid lubricants was even greater, and their use in a whole variety of applications was investigated.

The earliest fundamental investigations (3,4) demonstrated the two basic advantages of solid lubricants:

- They will withstand much higher loads than conventional lubricants.
- They will lubricate to higher interface temperatures.

Conventional lubrication is accomplished with thin films of physically or chemically adsorbed molecules on the metal surface. High loads and the accompanying surface deformation destroys these films readily. Temperatures of the order of 350°F cause their desorption from the surface. The solid lubricants having greater lateral stability can resist these loads and function up to their melting temperatures or oxidation points (5).

The basic disadvantage of solid lubricants is that they do not creep on surfaces and one removed from a portion of the contact area will not by themselves recoat the surface. Alternate means must be found to compensate for this deficiency.

These three factors must be kept in mind when considering potential applications for solid lubricants whether used as a resin bonded film, as a powder, or in oils and greases

Powders are only used in very special situations and generally in applications where special techniques, such as evporation, are used to apply precise film thicknesses.

Bonded solid film lubricants find applications in high load, low speed situations where the required life as measured in cycles is relatively short. They are also used in highly contaminated environments as a substitute for fluids which collect dirt and thus increase abrasive wear. Many of these applications are found in high-temperature or high-vacuum situations. They are particularly useful where fluid contamination is to be avoided. One of their most useful applications is the prevention of fretting between surfaces which are not normally designed to slip.

The addition of solid lubricants to greases and oils is known to improve the load capacity of the fluids, prevent seizure, and reduce the wear. This has also been substantiated in service. The presence of the solid lubricants also minimizes the abrasiveness of entrained dirt which collects in the fluid or grease.

Composite materials (i.e., materials having solid lubricant powders contained with a structural matrix) are self lubricating and can be a substitute for the system consisting of a bronze or steel bushing, lubricant reservoir, grease fitting and wicking system. This substitution saves not only on original costs but also reduced maintenance during the lifetime of the equipment. The composite material is very much like the bonded film in composition. The main difference is that the bonded film is applied only .0004" thick and is therefore life limited. The composite material on the other hand can be any thickness and will accordingly last longer if the extra wear can be tolerated. They are inexpensive and easy to replace and are finding increased usage in industrial equipment. Their increased utilization on naval aircraft certainly appears justified as will be discussed later.

It is not the intention here to review the applications for solid lubricants but rather to point out a few of the more significant developments which might be applied to reduce maintenance of naval aircraft. The extent to which they

have been exploited will be determined in the survey portion of the program. These items are described in the following sections.

## A. Sealing Plus Lubrication

Horwedel pointed out (6) that on small servo valves a solid film lubricant would serve two functions. That of lubrication between the piston and the cylinder and as a seal. During "run in" the coating, being relatively soft, wears to conform to the mating geometries. The increased conformity reduces the leakage. Although the films do have reduced life due to the presence of the fluids the loads are extremely low and the fluid provides the basic lubrication function. In addition, there has recently been increased interest in the use of solid lubricants on gaskets for essentially the same purpose. The film protects the gasket as the load is being applied and also improves the sealing effectiveness.

## B. Corrosion Protection Plus Lubrication

As will be discussed in the following section, solid lubricant films with increased corrosion protection have been developed. The U.S. Army at Watervliet Arsenal is now applying these films to gun barrels for corrosion protection. The film also provides protection from damage in handling. This type of dual usage may find increased applications in the future.

## C. Aid for "Run-In"

Some of the first uses of solid lubricants were to prevent surface damage during the critical "run-in" stages of bearing operation. However, the importance of this function was only recently emphasized when it was found that very large bearings could be installed "unground" and made to operate successfuly by first using a thick paste of solid lubricant. The same effect could be extrapolated to threads on major components. Thus it may be possible to eliminate finish machining in certain applications where solid lubricants are substituted.

## D. Rolling Contact Bearings

Beginning with the work of Devine (7) solid lubricants have found increased use in rolling contact bearings. It has been found that under the following

circumstances relatively long lives can be obtained:

Open clearances

Low velocites

Some resupply of lubricant

Proper materials for the temperature range of interest

The actual life is a function of the operating conditions, however lives of several thousand hours can be expected under normal operating conditions. Such bearings may find application in naval aircraft control bearings where conditions warrant their use.

## E. Cables

Control cables and structural components are apt to incur internal fretting damage from flexing. This damage then acts as a source for surface fatigue and eventual strand breakage. Externally the cables may rub against other surfaces with the same result. Solid film lubricants have found increased use in cables to prevent this sort of damage. If there is much cable replacement on naval aircraft this approach may be justified.

## F. "Difficult to Lubricate" Metals

It is well known that certain metals (titanium, aluminum, and magnesium) are difficult to lubricate with conventional lubricants. Unfortunately, these are the most frequently used metals in naval aircraft. It has been shown that certain solid lubricants are effective in preventing damage with these metals (8). It may be desirable to substitute solid lubricants in certain applications where these conditions exist. The solid lubricant may be either a bonded film or added to a grease.

## G. Other Applications

A recent publication by Lipp (9) lists those areas where solid lubrication is being considered on the supersonic transport:

Rolling Contact Bearings

Bushings

Track raceways
Wing control surfaces
Fasteners
Access doors
Ball screws
Cables
Pulleys

These could then be considered as potential uses of solid lubricants in present aircraft. In addition, the following new application areas have been suggested by Deemer (10):

Electrical connections
Instruments which must be frequently removed and replaced
Trays
Instrument bearings for slow oscillation

These are excellent suggestions which should be investigated.

## III. TECHNOLOGICAL DEVELOPMENTS IN SOLID LUBRICATION

The fundamental studies of the past twenty years have resulted in many product improvements and improved knowledge of the factors affecting solid lubrication. As part of this program a review was made to determine what technical advances have been made which could be applied to naval aircraft. It was found that there has not been a great deal of work published concerning the use of solid lubricants in oils and greases. What has been published is not particularly adaptable to naval aircraft. Most of the developments have been in the area of composite materials and bonded films. These are described in the following sections:

### A. Composite Materials

Very few fundamental studies have been conducted concerning the wear or frictional behavior of composite materials. Most of the efforts have been directed toward the development of new materials. However, it has been learned that the primary mode of failure with most plastic based materials is wear. This occurs when the surface temperature reaches a certain critical value unique for each material. In a general way this can be related to the operating conditions of pressure (P) and velocity (V).

Because polymer based composite materials are softer than the opposing metal surface, a transferred lubricant film is necessary for effective operation. This film fills the roughnesses of the metal and prevents excessive wear.

Solid lubricant filled materials can be lubricated with the same oils and greases as metals. In fact, it has been found that they will give much longer life on a small quantity of oil than metals. They have the further advantage that they can provide auxiliary lubrication in the event of lubrication failure.

One of the main advantages of self-lubricating composites is the variety of forms which are available. This means that almost any situation (except high temperature) can be accommodated in design. The material usually consists of a base material with additives. The additives are for the purpose of lowering

friction, reducing wear, improving the thermal conductivity or increasing the strength. The base materials and additives currently used are shown in Table 1.

TABLE 1

SELF LUBRICATING MATERIALS

| Base | Additives |
|---|---|
| Carbon | Teflon |
| Fluorocarbons | Graphite |
| Nylon | Molybdenum Disulfide |
| Polyacetals | Carbon |
| Phenolic | Oxides and Glass |
| Epoxy | Cloth or Asbestos |
| Polyimides | Bronze |
| Metals (Ag, Ta, Fe, Mo, Cb) | Babbitt |
| Bronze | Lead |
| Wood | Oil |

The form of the additive may be powder, fibres, fabrics or inserts.

The main disadvantage of the materials other than the temperature limitation is that they lack stability which may be required in certain applications. Many of the plastics will change their shape and dimensions when immersed in water or other solvents. Some of them change dimensions with time. The other disadvantage is that there are no standard materials with a number of suppliers. There are also few military specifications on self-lubricating materials.

It is generally felt that self-lubricating materials particularly the plastics are load limited. This is not ture. In fact, the first and one of the most important application of these materials have been as brake and clutch materials where high loads and shock loadings are used.

The advancements which have been made in this field have been in the area of new products which greatly expand the possibilities of the utilization of

of composites. These are described in the following paragraphs.

Several new forms of self-lubricating materials have been introduced which have increased the capability of composites. These may find applications at the NARF's. One such material is DU (Ref. 4i) which consists of a thin layer of porous bronze on a steel backing into which teflon and lead have been impregnated. This arrangement allows much heavier loads to be carried. Two other recent developments have been introduced which could save considerable time during rework. The first development is a film which consists of a solid lubricant composition with an adhesive backing. The resulting tape, which is purchased in role form, can be applied to a worn surface by hand pressure. Secondly, fillers are available, such as epoxy resins, which could contain solid lubricants. Worn surfaces may be filled with these materials and allowed to "set"; the surface would then be ground or buffed back to the correct size. Although such a practice would not be suitable in critical applications, it may suffice in many noncritical applications and effectively substitute for the more elaborate plating and spraying types of rework.

The second major development has been the introduction of higher temperature composites. These may be high temperature resins such as the polyimides which can operate up to surface temperatures of 750°F or metals filled with solid lubricants. In the latter category, materials have been developed by Boeing (11) which consist of the refractory metals filled with $MoS_2$. These have been used as inserts to lubricate rolling contact bearings at high temperatures.

The real advantage that these materials offer toward the objectives of this program is that they offer a backup in the case of neglected maintenance. If metal sliding surfaces are not lubricated they seize and cause structural damage. Self-lubricating materials, however, can operate satisfactorily with lubrication or without lubrication for a certain period of time without damage; thus considerable manhours could be saved.

B. Bonded Films

The improvements in bonded films can be categorized for the purpose of this

review as either those that give a longer wear life and would thus require less frequent servicing or those which simplify the film application process and reduce the processing manhours. Unfortunately, almost all the advancements have been in the former category and have been made at the expense of the latter so that the present films involve quite detailed processing and handling.

One of the most significant advances has been made in the development of new and improved films. The first films were pure films of lubricant burnished on the metal surface or bonded with corn syrup. Very soon, however, organic resins were utilized. These films consisted of approximately 40 to 50 percent lubricating pigment in a variety of heat curing resins. In many cases the pigment consisted of 90% $MoS_2$ and 10% graphite. In recent years, many new films have been developed from research investigations; the various categories are listed in Table 2.

TABLE 2

IMPROVED BONDED LUBRICANT FILMS

Air drying

High temperature resins

Inorganic resins

High temperature films

Oil resistant films

Corrosion resistant films

Low temperature cure

As far as this project is concerned, the most significant development has been the introduction of the air drying films. These are usually applied from aerosol cans and use vinyl, acrylic, or cellulose resins. These have been introduced via specification into the military system and have been

developed to the point where they have wear lives nearly equal to that of the heat cured films when correctly applied. A large number of manhours can be saved by substituting these films for the heat cured films. Particularly this would eliminate much of the part routing necessary with the conventional films.

Most of the development work in the past ten years has revolved around the evaluation of high temperature resins. This was brought about by the finding that film failure resulted more rapidly at interface temperatures above $400^{\circ}$ F due to resin softening. Since such temperatures are easily generated in many applications, higher temperature resins were sought. The silicones and the fluorocarbons were first developed (12) with later efforts being concentrated on amides and polyimides. Some of these have developed into commercially available films which give longer lives than conventional films under certain conditions (13) (14). These could be substituted for conventional films in those applications where high interface temperatures are generated.

Not only are the high interface temperatures generated by rubbing of concern but also high ambient temperatures. Films for use at temperatures above $700^{\circ}$ F were necessary and much development effort was expended toward this end. The first successful efforts were those of Devine (15) with inorganic silicate binders. Other similar films have also been developed (16) (17) and are commercially available. These are defined by a military specification but have not been used as extensively as they might. For higher temperatures $> 1000^{\circ}$ F, a number of films have been developed (18) (19). For the most part these have not been exploited commercially although there is a need particularly in engine applications.

The need for films that could be utilized in the presence of oils was recognized very early. To date, sufficient efforts have not as yet been expended to develop completely satisfactory films; however, some are available. These are primarily commercial developments which consist of oil resistant resins (with much shorter wear life) or nearly pure lubricant films. There is a great need for such films though the present ones may suffice in certain applications.

One of the most important recent improvements has been in the development of more corrosion resistant films. This work, which was carried out at Rock Island Arsenal, (20) consisted of the removal of graphite from the film and the addition of corrosion inhibitors. The recognition of the fact that graphite even in this form can contribute to corrosion has prompted its removal from other films. Thus, both graphite free and corrosion resistant films are now commercially available. It was also found that increased corrosion resistance would result with films with higher resin ratios and with films which are applied thicker. Thus, it can be seen that several techniques are available to have greater corrosion resistance in films. These would be particularly recommended for exposed areas of naval aircraft where needed.

One of the most significant advances has been in the area of material selectivity. Devine (21) at the Naval Air Development Center has shown that a given solid film lubricant will give a longer wear life when applied to certain metals. Furthermore, he found that the criterion for maximum effectiveness of a lubricant on a metal substrate, lies in the lattice matching of the two materials. An example of the performance benefit which can be gained is shown in Table 3 reproduced from Reference 21. Thus, it can be seen that a change in the base material can give an improvement in life of almost 2000%. Changing the base metal does not mean that the aircraft parts must be made from molybdenum. In rework it is usually necessary to "build up" worn parts by plating or spraying. This is usually done with nickel, however the same ends could be accomplished with molybdenum or some other favorable coating where solid lubricants are used. Some other effects of metal changes have also been noted which could be applied to practice where necessary. It has been suggested that solid film lubricants would be better applied to metals which react easily with sulfur so that an EP effect would result (22). Barry (23) suggested that a high thermal conductivity would lower the surface film temperature and thus increase life since there is a critical temperature where the film wear life is drastically reduced. Murphy (24) found a much improved wear life when an $MoS_2$ coating was added to porous iron. This effect is probably due to the reservoirs in the surface that hold additional solid lubricant. Thus, it can be seen that considerable

## TABLE 3

### EFFECT OF METAL COMPOSITION (RETAINER COMPONENT) ON BEARING PERFORMANCE LIFE

| | |
|---|---|
| Apparatus: | High Speed Bearing Performance Apparatus |
| Specimen: | 204 Size Ball Bearing, AISI M-10 Balls and Races, Retainers (as shown) |
| Load: | 5 lb. Thrust, 3 lb. Radial |
| Speed: | 10,000 rpm |
| Temperature: | 750 F |
| Solid Film Lubricant : | $MoS_2$ (71 wt.%), Graphite (7 wt.%), Sodium Silicate (22 wt.%) |

| Retainer Designation | Major Metal | Alloy Constituents | Retainer Hardness | Performance Life (hr) |
|---|---|---|---|---|
| Inconel X | Ni | Fe,Cr,Ti | $R_B81$ | 60 |
| Ti-140A | Ti | Fe,Cr,Mo | $R_C37$ | 98 |
| AISI TI | Fe | W,Cr,V | $R_B98$ | 139 |
| AISI TI | Fe | W,Cr,V | $R_B98$ | 132 |
| AISI 430 | Fe | Cr | $R_B76$ | 143 |
| S-Monel | Ni | Cu,Fe,Si | $R_C36$ | 171 |
| AISI M-10 | Fe | Mo,Cr,V | $R_B98$ | 280 |
| AISI M-10 | Fe | Ti,Zr | $R_B94$ | 310 |
| Climelt TZM | Mo | Ti,Zr | $R_B94$ | 1069 |
| Climelt TZM | Mo | Ti,Zr | $R_B94$ | 1148 |

life improvement can be realized with the use of the optimum base metal.

Very early in product development it was recognized that surface roughening would increase the wear life of both bonded and unbonded films. For example, see Figure 1 taken from Reference 25. Generally, it was felt that the increase gave greater adhesion due to the increased contact area however from the work of Devine (21), this view has been somewhat modified to that of a surface reservoir effect. That is, the interstices hold the excess lubricant to supply to the asperity tips. Recently this effect has been studied by Lancaster (26) who found that the wear life of unbonded films was a maximum of 30 CLA. The optimum condition was to have the asperities equal in height and uniformly distributed on the surface. This would, of course, strengthen the reservoir concept but more important, it provides a guide to the proper type of surface finish and suggest a more uniform shot for surface roughening which would provide such a finish. Devine (27) has investigated the effect of various surface roughening treatments on the wear life. It was found that the vapor blast is much more desirable under these conditions of operation giving six times the life with a sand blast finish and that the iron shot (120 mesh) or the SiC (60 mesh) was much better than the other compositions. In particular, the use of glass beads should be avoided.

The use of chemical pretreatments to increase the wear life came about very early in product development. Barwell and Milne (28) first published on this effect in 1951. It was quickly adopted by industry and more or less standard pretreatments are suggested by all film suppliers. Although work has been done to optimize the surface treatments, it is not of sufficient magnitude to justify changes at the present time. Perhaps the most significant result was that of De Sapio (29) which showed that under oscillating conditions that the phosphate coating did not add significantly to the wear life of the most common films over just the vapor blast pretreatment. Although this may be a very special situation, it does point out the fact that the surface pretreatments may not always be needed particularly for non-critical applications where only a relatively few sliding cycles are accumulated during the lifetime of the part. Much of the research and development effort has been directed toward improved wear life and most suppliers invariably recommend all pretreatments.

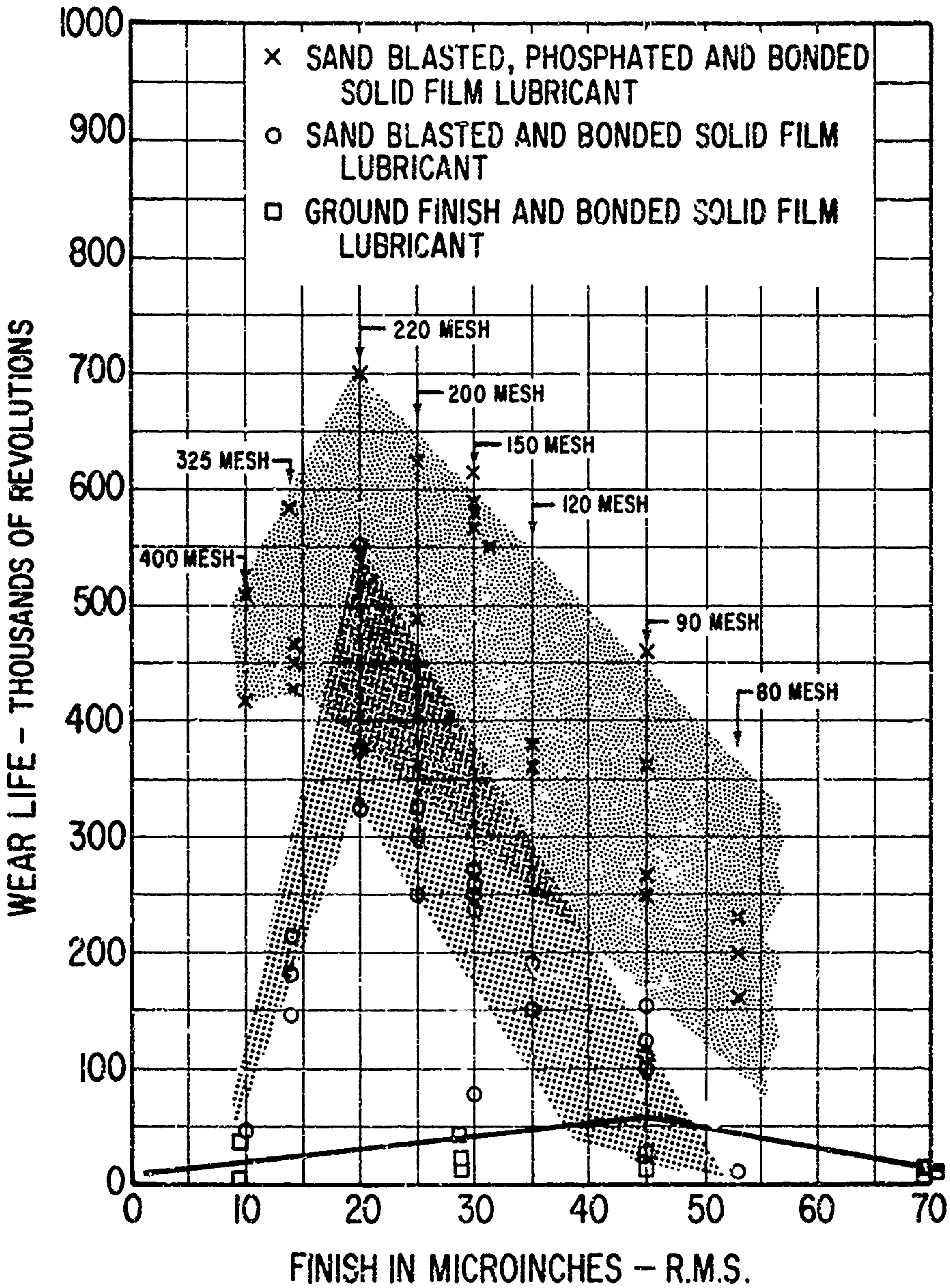



Fig. 1 The Effect of Surface Finish on the Wear Life of a Solid Lubricated Film (Reproduced from Ref. 25).

Considerable time could be saved if these pretreatments were eliminated. It is felt that this can be for non-critical applications. Some suppliers have experimented with substitute treatments for chemical pretreatments. It is assumed that the main purpose of the chemical pretreatment is to increase the bonded film adhesion. Accordingly, other methods of increasing resin to metal adhesion have been considered for example, chelating agents. At least one supplier is recommending silane pretreatment where chemical pretreatments are not desired. Since these are simpler to apply, they may find application at the Naval Air Rework Facilities. Another development which has been reported and has found increasing use is that of applying the bonded film over cadmium plating where increased corrosion protection is necessary. Murphy (24) reports that zinc phosphate on cadmium plate is the best substrate for maximum corrosion resistance. This may find application where corrosion with solid films are a problem.

It has always been known that extreme care must be taken to insure proper cleanliness in the processing and use of bonded solid film lubricants. This includes cleaning before and after each step in the processing, protecting the coated part from contamination, and insuring that no oil or grease is applied to the coating upon reassembly. There have been very few changes in this requirement through the years. The only significant development other than the oil resistant films previously mentioned is that most solid film lubricant suppliers have found it necessary to institute rigid controls on the handling and transporting of parts. Gloves are always required and the parts are carried and stored in 4 mil polyethylene bags. This is discussed in more detail in the following section.

Very little research has been done to optimize the bonded film application process, however many practices have become accepted as the most suitable procedures for film application. After thorough mixing with the recommended solvent (where specified) in a separate container, the solid lubricant film should be applied approximately as shown in Table 4. It would be highly desirable for these materials to come premixed.

The actual spray method per coat is to apply several cross passes of the

TABLE 4

METHOD OF APPLICATION OF BONDED FILMS

| | |
|---|---|
| Equipment | Not Standardized |
| Pressure | 30-50 psi |
| Distance | 8 to 10 inches |
| Spray Condition | Reaches Surface Wet-Drys Almost Immediately |
| Total Thickness | .0002 to .0005 |
| Thickness Per Coat | .0001 or Less |
| Number of Coats | 3 or More |
| Time Between Coats | Several Minutes |
| Air Dry Time Before Cure | One-Half Hour |
| Pretreatment | Not Standardized |
| Cure at Elevated Temp. | Not Standarized |

---

specimen. The spray gun should be kept moving so that a uniform coating is applied.

Of these, the most important is the thickness control. It is well known that the wear life is shortened drastically if too little or too much is applied. The natural tendency is always to apply coatings which are too thick (just to be sure there is enough there). Coatings which are applied thicker than .003 inches will flake from the surface. Of course, it is very difficult for anyone to judge coating thickness. Some simple guides can be used by the sprayer. A .0001 coating will only take approximately one second to apply. A coating of this film thickness will completely darken a sheet of paper placed behind the part.

The second critical area is in the mixing. The solids have a tendency to settle and unless continuously mixed the resin/sol'ᵢ ratio will change drastically. Accordingly, most sprayers put marbles in the gun and develop the habit

of shaking and spraying at the same time. This also assists in applying more uniform coats.

The main problem has always been to find some method of insuring that the above procedures are followed. The industry has been plagued with the fact that almost invariably the sprayer will decide for himself the best method of film application. He wants to apply the best looking film, which usually has a very poor wear life. The system which has evolved to prevent this is the "qualified sprayer" concept. The sprayer is instructed in the proper method of film application and cleanliness standards and the reasons why these procedures are necessary. Wear life tests on his coatings are carried out to see if they fall between established norms. If they do, he is then given a certificate of qualification. Thereafter he is periodically re-evaluated to determine if the coatings he applies have adequate wear lives. Furthermore, to insure cleanliness and the elimination of processing steps some suppliers "tag" parts. That is, each part carries a tag which gives the step-by-step process to be followed in pretreatments and in film application. At each step, a signature is required to show that the step was indeed completed. All parts are carried in containers to insure their cleanliness. Such techniques may be necessary at the Naval Air Rework Facilities.

There are several new developments in film application which have practical potential. Both Jones (30) and Lipp (31) have reported that at light loads the wear rate is directly proportional to thickness. This is in contrast to the heavy loads where the maximum wear life is found with a .0003 inch coating. This result shows that with certain applications, thicker coatings may be used to extend the wear life.

A number of new techniques have been developed for applying films. These are sputtering (32), flame spraying (33), ion plating (34), and evaporation and conversion (35). These techniques are particularly useful for applying pure films or where rigid thickness control is desired. These may find application in certain special situations on naval aircraft such as instruments or higher temperature situations, however the processes are quite complicated and would require sending out parts for treatment.

An interesting study has recently been reported by McConnell (36). The purpose of the work was to try to devise means to extend the wear life of a given coating. It is known from research studies that at heavy loads most of the film wear takes place during the first few minutes of operation due to compaction and flaking. Thus, the authors speculated that if the applied film could be compacted and made more dense before running a longer wear life would be obtained. Two approaches were evaluated: mechanical compression and void filling. It was found that both polishing and rolling the film increased the wear life, however double deposition of the film to fill the voids gave an order of magnitude increase in life. Although this was a very special film, the same results might be applicable to more conventional films.

To date, there has been no general studies to optimize the design of sliding contacts which use solid film lubricants. It is known, however, that certain aspects of the design will influence the wear life. It is usually recommended, where possible, to select opposing metals which have good wear compatibility; that is, materials which will slide without surface damage when unlubricated.

A recent review has been published which outlines techniques for selecting such materials (37). Essentially sliding surface damage is reduced with those materials which have high hardness, low ductility, form lubricating oxide films, and have little tendency to alloy. It is also recommended that for maximum wear life both surfaces should be coated. Care should also be taken to remove sharp edges which can scrape away the film. Particularly severe is the case of a hard rough surface which can almost instantly abrade away a bonded solid film. Dirt in the contact area will have the same effect; wherever possible operation should be in a clean, dry atmosphere. From more recent work, it appears that there is an optimum <u>surface</u> temperature for maximum wear life (38). This temperature should be high enough to insure complete film drying but not so high to soften the binder; this means a temperature of between 200° F and 400° F. It is possible to change the surface temperature by changing the area of contact since the rubbing temperature is directly proportional to contact area.

In Reference 39, the effect of surface finish and hardness on wear life was

studied. It was suggested that the generated wear particles of the film have a damaging effect on the remaining film. It was further suggested that the surface be grooved to remove the debris. This would also be beneficial in removing the dirt trapped within the contact area.

In another significant development (40) it has been shown that the wear life is greatly increased when operation is in argon rather than dry air. Although it is very difficult to operate in an argon atmosphere, it does point out the advantage of solid lubricants for applications where there are inert atmospheres.

For design, it is necessary to describe the effect of surface shape on the wear life. Unfortunately precise data does not exist, however, in several instances the wear life of the same film has been evaluated on several different rigs under identical conditions. For example, Murphy (24) showed that based on film life (feet of travel) that the LFW-3 test machine is the most severe followed by the Falex, Shell four ball, and the Timken which is the least severe. Although other factors could be involved, it is interesting to note that the LFW-3 has continuous contact (flat ring rotating against flat); the Falex, 4 point contact; the 4 ball, 3 point; and the Timken, one point contact. This suggests that small areas of contact might be more suitable than a completely conforming geometry such as is found in many applications such as journal bearings, hinges, slides, etc.

Thus, it can be seen that a number of means are available to extend the life of solid film lubricants which can extend the rework interval. Most important are surface roughening, cleaning, and thickness control. Beyond that further improvements can be made by consideration of the factors listed in Table 5.

## TABLE 5

### SIGNIFICANT RECENT ADVANCES IN SOLID LUBRICANTS

- Importance of material selectivity in extending wear life
- Utilization of pretreatments
- Improved surface roughening processes
- Recognition of the need for purity and cleanliness standards
- Importance of film density
- New application techniques for special situations
- Recognition of importance of design factors

## IV. MATERIALS AND LUBRICANTS IN USE

From initial visits to the Naval Air Rework Facilities (NARFS), it became apparent that there were few problems associated with solid lubricants in greases and oils. Military specifications are used and the products are generally available. Specific problems associated with their use are discussed later. Solid lubricant composites are rarely used so they present no general problems; their wider use, however, is strongly recommended as will be discussed later. Most of the problems centered on the use of bonded films. These then were considered in detail.

There are approximately 25 companies which sell bonded solid film lubricants. For the most part these are small, not very well known, companies. There are many more companies which sell under license from these organizations. These companies market approximately 110 solid film lubricants usually under a trade name which does not identify the company. Although these lubricant films may be placed into general categories, there are some which are quite unique and are made for very special applications. Some of these films are clearly better than others for a given application but no film could be graded superior to others for a majority of applications. It must be remembered that each company uses a specific test rig to develop his products. His products are therefore optimized for that rig and applications which simulate it.

From this wide variety of different compounds the military have selected a number of different types of lubricants based upon performance specifications. A brief outline of these specifications is given in Table 6. The qualified products of several of these specifications are listed in Table 7.

Every two years the products must be requalified so this list will change from time to time. In theory, all products manufactured for the government would use a government specification material. These then could be reapplied in rework or a substitution made for another "qualified" product.

It was found that to a large degree this system has broken down. The compounds

TABLE 6

OUTLINE OF SPECIFICATIONS

| Specification | Description | QPL |
|---|---|---|
| MIL-M-7866B | $MoS_2$ Powder | No List |
| MIL-G-6711 | Graphite Powder | No List |
| MIL-L-8937A | General Purpose Heat Cured Bonded Solid Film Lubricant | Yes |
| MIL-L-23398B | Air Drying Solid Film Lubricant | Yes |
| MIL-L-81329(ASG) | Extreme environment (-300 to 750 F) bonded film. $MoS_2$, Graphite, Sodium Silicate | No List |
| MIL-L-46010(A) | Corrosion Resisting Heat Cured Bonded Solid Film Lubricant | Yes |
| MIL-L-46009 | Replaced by MIL-L-23398B | |
| MIL-L-22273 | Replaced by MIL-L-8937 | |
| MIL-L-25504 | Replaced by MIL-L-8937 | |
| MIL-G-26548 | Air Dry Resin Bonded Graphite Film (withdrawn) | |
| MIL-G-21164C | 5% $MoS_2$ Grease-Diester Oil | Yes |
| MIL-G-23549A | 5% $MoS_2$ Grease-Mineral Oil | Yes |
| MIL-G-17745 | 5% Graphite in Polygycol | No List |
| MIL-L-25681C | 50% $MoS_2$ in Silicone (Paste) | No List |
| MIL-L-3572 | 2% or 10% Graphite in Mineral Oil | No List |
| MIL-T-5544 | Thread compound 50% graphite in petrolatum | No List |
| MIL-A-907D | 50% $MoS_2$ antiseize compound | |

## TABLE 7

### QUALIFIED PRODUCTS

| MIL-L-8937A | MIL-L-23398B | MIL-L-46010A |
|---|---|---|
| Acheson Colloids DAG254 | | Adreco Adrecolube 13 |
| Dow Corning Molykote X106 | Electrofilm Lubri-Bond "A" | Chester Chemical Co. Cal-40 |
| Anolube A101 | Hohman Plating Surf-Kote A-1625 | Dow Corning 3400A |
| Drilube Spraymix 1A | Lubrifilm 600A | Dri Lube 6A |
| Electrofilm Lub-Lok 5306 | | |
| Everlube 620 | | Electrofilm Lubelok 2109 |
| FelPro C640 | | Everlube Ecolube 642 |
| Henderlube 402A | | FelPro C-651A |
| Hohman Surf Kote M1284 | | H.A. Henderson Henderlube 413 |
| Lubeco M-390 | | Kalgard RA |
| Lubrifilm LF 700 | | Lubrifilm LF-710A |
| National Process Industries NP1-14 | | Lunex Co. Spra-Sta "E" |
| Poxylube 500M | | Sandstrom 9A |
| Kalgard FA | | |

| MIL-G-21164C | MIL-G-23549A |
|---|---|
| Castro Oil Castrolease MSA(c) | Std of Calif. Special Launching Pad Grease |
| Electrofilm Electromoly 11 | American Oil Super Mil Grease 94532 |
| Everlube 211-G | Hulbert Oil, Hulmoly 10301 |
| Royal Lubricants Royco 64C | International Lubricants Code 20443 grease |
| Shell Oil Aeroshell 17 | Shell Oil Catapult FP Grease |
| Std. of Calif. Calol 4056 | Royal Lubricants Royco 49B |
| | Southwest Grease Code 16710 |

in actual use at the NARFS are listed in Table 8.

TABLE 8

SOLID LUBRICANTS IN USE

| Location | Regular Use | Specials |
|---|---|---|
| 1 | Dag 213 | Molykote 106; Electrofilm 4856 |
| 2 | Fel Pro C-200 | |
| 3 | Dag 154 + Phenolic Resin<br>Electrofilm 5396 | Dow X15 |
| 4 | RIA-9A<br>Electrofilm 4396<br>Electrofilm 2006<br>Fel Pro C-200 | Many Specials |
| 5 | Electrofilm 4396 | |
| 6 | Dag 154 + Phenolic Resin<br>Fel Pro C-200 | Dow X15 |
| 7 | Electrofilm 5396<br>Electrofilm 4396 | Electrofilm 2006 |

This information was obtained from the foremen of the facilities which apply the films. This list may omit some of the little used materials, however, it may be considered generally correct particularly in regard to those regularly used.

Several points can be made concerning these lubricant films.

- Only one or two lubricant films are in general used at each facility
- In general, these lubricants are not on the qualified products list.
- The graphite containing films are corrosion prone and could be eliminated.

- Many of the extensively used lubricants are essentially the same and could be eliminated.
- Wider use could be made of more recently developed films which are more corrosion resistant and will withstand higher temperatures.

It is quite obvious that an improved product mix could be instituted at the NARFS. The non-qualified products should be eliminated and the military specifications used as guides for the types of films which should be used. The specifications are "up-to-date" and there are almost no companies who have introduced greatly superior products. Although improvements could be made in the specifications, they do represent the latest technological advances.

It is valuable to consider the realities of the present system since some improvements and recommendations can be made to eliminate the introduction of non-qualified products. Supposedly new films are introduced via a Local Engineering Specification where there is sufficient justification for their use. An examination of the LES's from the NARF's showed that they are well written technically and whenever possible follow military specifications. Unfortunately, this is not the way new films are introduced at the NARF's. Generally the production shops follow the manuals and all too frequently the manuals specify proprietary compounds. In many instances the proprietary compounds are specified for high usage items such as blade roots. These films then become dominate since it is unlikely that a sprayer would go to all the trouble to change the lubricant for one small part. Some examples of proprietary compounds are as follows:

- NAVAIR 02B-100AA-6-2 PAR-6-396 states, "Apply Fel Pro C-200 Per SPOP 146 or Ease off 990....
- NAVAIR 02B-10ADE-503 APPENDIX XIV defines the mixing of Dag 156 with Mil-R-3043 (phenolic resin) to apply to blade roots
- NAVWEPS 03-95B-69 specifies the use of molykote wear in compound
- NAVAIR 03-110-Ft 4 specifies only Everlube (P/N 216288) for a certain application

It was found that all variations were specified in the manuals; qualified products identified by trade names rather than military specification, non-qualified products are specified, films identified only by a drawing number or by a vendor specification and some films identified only as "dry film lubricant".

Although this may seem like a small inconvenience when the sum total of all types of products is considered, a great deal of valuable engineering time is wasted "chasing down" proprietaries, learning what they are, and substituting more readily available or qualified materials. Since engineering hours are the most valuable, important manhours saving could be made by removing these proprietary compounds from the technical manuals. At least make sure that new manuals do not make this mistake.

Under these circumstances two courses of action are open, neither of which is satisfactory. If the manuals are followed, a wide variety of lubricants are introduced with all the associated problems of procurement, changing of lubricants for each part sprayed, storage, shelf life effects and different processing procedures for each film. The second course of action is to change all lubricants to a few which they have selected. This, however, requires a great deal of valuable engineering hours to determine the composition, intent of the film, and a suitable substitute. In many instances, this information may not even be available to the engineer. Instances have been reported where the companies would not release this information. It also requires an "in depth" knowledge of solid film lubrication. Many examples were found where a large number of engineering hours were spent replacing an unsatisfactory or unattainable film.

It is clear that if maintenance engineering hours are to be saved that the removal and elimination of proprietary compounds in aircraft manuals would be an excellent place to begin. This, of course, is a long range solution which will require some time to implement. For the short range, it is recommended that a survey be made of the solid film lubricants commercially available. These should be categorized into interchangeable products which

can safely be substituted for each other. The following categories are recommended:

- General Purpose (MIL-L-8937)
- Corrosion Resistant (MIL-L-46010A)
- Oil Resistant --
- Intermediate Temp. Range (MIL-L-81329ASG)
- High Temperature --
- Aerosol (MIL-L-23398B)

Four of the categories are now covered by military specifications and two extra categories have been added because it is felt that they are needed immediately at the NARFS.

The most obvious need is for oil resistant films. Very rarely has it been found in this survey that oil was not applied to solid film lubricants either in rework or in service. Mechanics have been trained to lubricate parts, Furthermore, an aircraft operates in an oil environment; leakage is the rule rather than the exception; preservative oils are sprayed on the aircraft; oil creeps from one surface to the other. To expect a solid film to remain oil free is not very realistic.

Secondly, there is a need for films which would operate in oils, hydraulic fluids, greases, and fuels. Numerous examples have been found where such coatings could improve the part performance. Although outstanding films are not yet available, the best present day coatings should be so specified and development efforts directed toward improved coatings.

Numerous examples have also been found where high temperature dry films could be used to advantage. (> $1000^{\circ}$ F). At the present time, silver plate or plasma coatings are used. They do not have the low friction of solid lubricants and are much more difficult to apply. Although much more improvement in high temperature films is necessary there is a sufficient number available to be introduced into the system as previously discussed.

In a larger sense, however, even as many as six films seen unnecessary. With the increasing knowledge which has been available in the past few years on the wear behavior of solid lubricant films, a multi-purpose film appears to be within the realm of possibility. The importance of long wear life has been overemphasized in present day development. For many applications, it is not necessary. Large sacrifices could be made in wear life to obtain a coating which would cover, for example, the first four listed categories.

This survey has also brought to light some additional information concerning the present direction of research and development. In almost all cases industrial research and development has been directed toward improving the life of films. This is certainly a worthwhile objective but somewhat illusionary. Life is being improved on test machines which may not simulate practice and by more elaborate pretreatments, which are time consuming and unnecessary. The results of this survey indicate that it would be better to direct research and development efforts toward films which are more "forgiving" toward surface contamination, less dependent upon surface pretreatments and less sensitive to film thickness. It is unrealistic to believe that people primarily engaged in paint spraying, having rotating assignments, and lacking technical knowledge of the subject will spray films of .0002 to .0005 inch thickness. It is the general feeling, in the industry, that it takes almost a year to train one man to spray correctly. This is impractical and should be unnecessary.

Many solid film lubricants carry a six month shelf life. Present research efforts have been directed toward extending this life to two years. However, as was pointed out at Alameda, lubricants now supplied through normal channels may have extensive delays both in the vendors distribution system and in the Navy's supply system. As a result, solid lubricants can arrive in the shop later than the shelf life date on the can. Until the shelf life is extended, it is recommended that solid lubricants be obtained on open purchase, directly from the vendor. The vendor should be required to certify that the products conform to military specifications.

In summary, it has been found that in general unqualified products are being used in the rework of naval aircraft. These are specified in the manuals.

Since there is no reason to believe that these films are essential to the application they should be eliminated from the rework facilities and from the manuals and qualified products substituted. To assist in this transition, it is recommended that a technical manual be prepared on solid lubricants. It should be similar in scope and purpose to the "Aircraft Cleaning and Corrosion Manual" (NAVAIR 01-1A-509) and the manual on "Maintenance of Aeronautical Antifriction Bearings" (NAVWEPS 01-1A-503). At the present time, no such publication exists within the government or the open literature. This manual should emphasize those areas where information would be most valuable to the NARFS. That is, a list of current solid lubricants categorized into the six general areas of usage which emphasize the specifications. Such information would facilitate transitions to qualified products. The manual should also contain accumulated information on corrosion effects and film failure for benefit of engineering. Other purposes of the manual will be discussed later.

Research and development efforts should be directed toward multi-purpose lubricants and to films which are less sensitive to pretreatments.

## V. PROCESSING

### A. Introduction

It is well known that the processing to apply bonded films is critical whether the film be applied from an aerosol can, be air dried, or be heat cured. Industry has had many problems in this area; there is invariably a tendency to take short cuts to save manhours or processing costs. This leads to poor films with short lives and failed parts. In fact, this problem became so serious that several companies gave up the practice of licensing film applicators because of their inability to adequately control the process. Some of these same problems became apparent in this survey and recommendations are made to improve those areas. Essentially, these are the same steps which industry finds necessary to take in their own shops.

The processing consists of a number of independent steps as follows: stripping, cleaning, surface roughening, pretreating, film application, and curing. Of these, cleaning and surface roughening are the most important. If these are not adequately carried out, the applied films will be practically worthless. Some compromises are permissible in the other areas but at the sacrifice of wear life. These effects are discussed in the following sections.

### B. Local Process Specifications

The local process specifications (LPS) were collected at each NARF and reviewed. They were of two forms, a general one which covered all films and processing or one which covered each film individually. Without exception, they adequately covered the various processing steps in sufficient detail and with sufficient technical accuracy. If these LPS's were followed in practice, few problems would arise. Unfortunately, it has been found they are not followed and many short cuts are taken in processing. The reason for this is uncertain however, a probable suggestion is as follows: There are many applications where solid film lubricants are used where only a few sliding cycles are accumulated during the required operating life. However, in specifying these films the designers have followed the vendor recommendations and called for elaborate pretreatments. The users find by experience that all of this is not really necessary so the

pretreatments are eliminated as cost savings. Unfortunately, they do not differentiate between critical and non-critical applications and short cuts become widespread. Very quickly films begin to fail and they are replaced with different forms of lubrication. Thus, it is believed that the unnecessary detail specified where it is not needed leads to short cuts being taken on all applications. This is, however, a difficult problem to solve since most designers do require a substantial safety factor. About the only solution lies in direct training of the sprayer so that he understands the consequence of poor films.

## C. Facilities

At most of the NARFS the film application is done in the paint shops. At all of the NARFS this is located in the engine overhaul section. At several of the NARFS a second facility is applying films to non-engine parts. Aerosol spray cans are used extensively in various shops throughout the NARFS. The films are applied at the paint spray booths by all personnel on a random basis. However, at several facilities one man is assigned to apply dry film lubricants. At Pensacola, a portion of the paint shop and one spray booth has been designated a special coatings facility where on dry film lubricants, teflons, wrinkle finish, and ceramics are applied. This is a good practice since one man assigned to this facility can become familiar with the rather special technology of these films. In the paint shop only the cleaning, film application, and the curing are carried out. The pretreatments and the surface roughening are done elsewhere.

Each part being reworked carries a routing tag which gives among other things the part number and specifies the various steps in its rework. This tag routes the part to the cleaning and finishing shop for stripping, cleaning, and surface roughening; to the plating shop for pretreatments, and to the paint shop for film application. One point can be made concerning these routing tags. Most of them merely specified "apply dry film lubricant" instead of calling for a specified lubricant or military specification. In reality, this practice leaves the selection of the lubricant to the sprayer. He will use what is in the spray can at the time. It is recommended that the actual film be called

out on the cards.

The specific spraying equipment used at each NARF is listed in Table 9. Although there is considerable variation in the practice, it has not yet been shown that the actual equipment is critical to film life unless the sprayi is improperly done. However, since the spray gun does influence the metho of application it would be desirable to standardize the equipment so that film application can be standardized.

The curing is generally done in large walk in furnaces or in rack furnaces where parts move through the furnace at a certain rate on a belt. The time in the furnace is usually one half hour. None of the paint shops have small furnaces which could be used for one or two parts.

TABLE 9

SPRAY EQUIPMENT IN USE

| Location | Make | Model | Nozzle |
|---|---|---|---|
| 1 | DeVilbiss | TGA | #90 Aircap |
| | DeVilbiss | MBC 502 | #765 Aircap with 444 needle |
| 2 | DeVilbiss | MBC | #30 |
| | Binks | 18 | 66SD |
| 3 | Binks | 26 | 78SD |
| | Binks | 18 | #66SD with #65 needle |
| 4 | DeVilbiss | 501 | #30 |
| 5 | DeVilbiss | MBC-510 | #30EX |
| 6 | DeVilbiss | --- | #30 |
| 7 | DeVilbiss | EGA Series | #365 Nozzle |

## D. Stripping

The military specifications do not describe methods of stripping the coatings. Although it is a simple matter to strip unused coatings, once sliding has taken place and the solid lubricant has been ground into the surface it is much more difficult to remove. The present practice developed at the NARFS is to clean the parts in alkaline tanks and to strip the coatings with walnut shell blasting or some other mild abrasive. Film not removed in this manner is removed in subsequent abrasive blasting operatings. Although there is no serious problems in this area it would be advisable to include some guidance on this subject in future revisions of the specifications. This is particularly true for teflon which is inert to most organic solvents.

Since the stripping of coatings and their reapplication requires a large number of manhours and considerable moving of parts the question may be asked if stripping is necessary or if the new film could be reapplied over the old with only some cleaning process. Such a practice would be feasible where inspecting for cracks is not required. Since the practicality of this idea is not discernable from the technical literature, discussions were held with the various solid lubricant research laboratories on this subject. It was found that almost no experience is available to use as a guide except from the Naval Air Development Center where direct reapplication of a solid lubricant film was used to keep an engine running. The general feeling, however, was that it is feasible to provide a method for the effective reapplication of new film applied over old [illegible].

In the A-3 manual (NAVAIR 01-40ATA-2-1) Figures 1-16, a dry film lubricant touch up procedure is recommended as follows:

- "If the dry film lubricant is scratched, marred or worn touch up as follows:

    (a) Clean thoroughly all areas to be touched up by washing twice using clean clothes moistened with solvent

    (b) Mask

    (c) Spray on dry film lubricant

    (d) Inspect - test adhesion

Thus, there is some precedent for merely touching up used films. However, it may be safer to run a few simple experiments to determine the merit of this approach.

E. Cleaning

As previously discussed, adequate cleaning is essential to proper film adhesion. With poor adhesion the coating will flake off the surface under the smallest applied load. Most manufacturers recommend degreasing with perchlorethylene or Trichlorethylene with vapor degreasing as the preferred method. The local process specifications recommend essentially the same procedure. Whether this is consistently done in production could not be ascertained in this survey, however in many instances the parts waited at the spray booth to be coated and were not degreased immediately prior to spraying. They were frequently handled without gloves which can seriously contaminate the surface. It has also been found that degreasing should follow the grit blasting since the grit very quickly becomes contaminated in service. Any one of these practices can appreciably shorten the wear life of the coating. To such a problem, there are only two solutions: adequately instruct the sprayers so they are familiar with the consequences of contaminated surfaces and establish some quality assurance to measure the effectiveness of the sprayed coating. These will be discussed later. It would also be of benefit to place vapor degreasing equipment in the paint shop so that there is a greater tendency to degrease immediately before applying the lubricant film.

F. Surface Roughening

This processing step is of equal importance to surface cleanliness in determining the coating adhesion and ultimate life. Most vendors recommend sand blast or vapor blast with a few recommending a 120 mesh grit. The LPS's generally recommend a vapor blast although two facilities use glass bead blasting while one recommends steel shot. Based upon recent research results previously discussed, it may be well to replace the glass beads with another method of roughening.

Inspection of parts reaching the paint shop indicated that many were only

turned or ground and no vapor blast treatment was used. Discussions with shop personnel yielded the fact that rarely were surface roughening treatments used with aerosols. Although the survey could not yield how widespread this practice is, sufficient evidence was seen to indicate that some corrective action should be taken.

## G. Pretreatments

Almost all research workers in this field and all vendors recommend the use of pretreatments immediately prior to the applications of the solid film lubricant. These chemical pretreatments (phosphate for steel, anodize or alodine for aluminum, chromate for copper, etc.) have been shown to increase the adhesion of solid lubricant films and their wear life. The use of pretreatments has become so well accepted that it is almost universally used. The LPS's have all recommended their use at the NARFS. In this survey, very little evidence could be found that pretreatments were actually used in production. Most parts waiting to be sprayed were not pretreated. Although this practice, if general, is in conflict with all recommendations it may not be too serious. As previously discussed, it adds somewhat to wear life but its usefulness has been somewhat overrated. In some applications it can safely be eliminated but not all and certainly not on critical applications such as blades or engine control surfaces. If a film is worn through the resulting surface damage can initiate fatigue fractures.

## H. Film Application

The normally accepted procedure for spraying has been discussed previously. There is, however, considerable latitude in procedure as long as uniform films of thickness .0002 inch to .0005 inch are applied. The critical parameter being the spraying time and the constant agitation of the spray can. The film application techniques were viewed at most NARFS. They varied considerably from person to person as might be expected. In most cases, the film was put on in one coat with many passes with the correct air pressures and sufficient agitation. However, as is usually found this procedure results in film thickness which are too large. In fact, most sprayers said that they applied the coating 1 to 2 mils thick. It is better to put on several coats with just a

few passes. To adequately judge the film thickness, one coat is applied until the part being sprayed or the surrounding masking paper just appears completely covered. This applies approximately .0001 inch. The part is then air dried and two or three more coatings are applied using the same amount of spraying time as the first. Learning this technique and the other processing procedures is a matter of training followed up by some technique of quality assurance. Industry checks the sprayer by occasionally measuring the wear life of coatings he applies, however in this case an adhesion test and a thickness check would suffice.

At two NARFS the sprayers had prepared a notebook for their own use which listed the part numbers, names, and originating shops of all parts to be dry film lubricated. It also included the lubricant to be applied and the heat curing temperatures and times This is very commendable for the obvious reasons that it maintains a consistency of practice and for the not so obvious reason that a permanent record is established as to what films have been used. The writing of such a record is not time consuming and would save a large number of manhours in the long run. It would also make film substitutions based on new technology easier to implement. For this reason such a record is recommended for all solid lubricant spray facilities.

## I. Curing

Unfortunately every solid lubricant manufacturer recommends a different cure (temperature and time) for every solid lubricant. A graph giving the times and temperatures for the 86 resin bonded films is shown in Figure 2. A great variety of cures exist. This means that where many solid lubricants are to be used (as is now necessary at the NARFS to conform to the manuals) each part becomes a special situation. For one small part which must receive a special coating cure a large oven (a bank of ovens are not available) must be reset to a given temperature and utilized for a long time (1 to 2 hours) for a single purpose. This seriously limits the number of parts which can be cured in one shift. <u>It would be much more satisfactory if all films could be cured at the same temperature and for the same amount of time, the shorter the better.</u> More parts could then be done at one time. Actually since there is considerable latitude in the cure such a change is possible; higher temperatures and

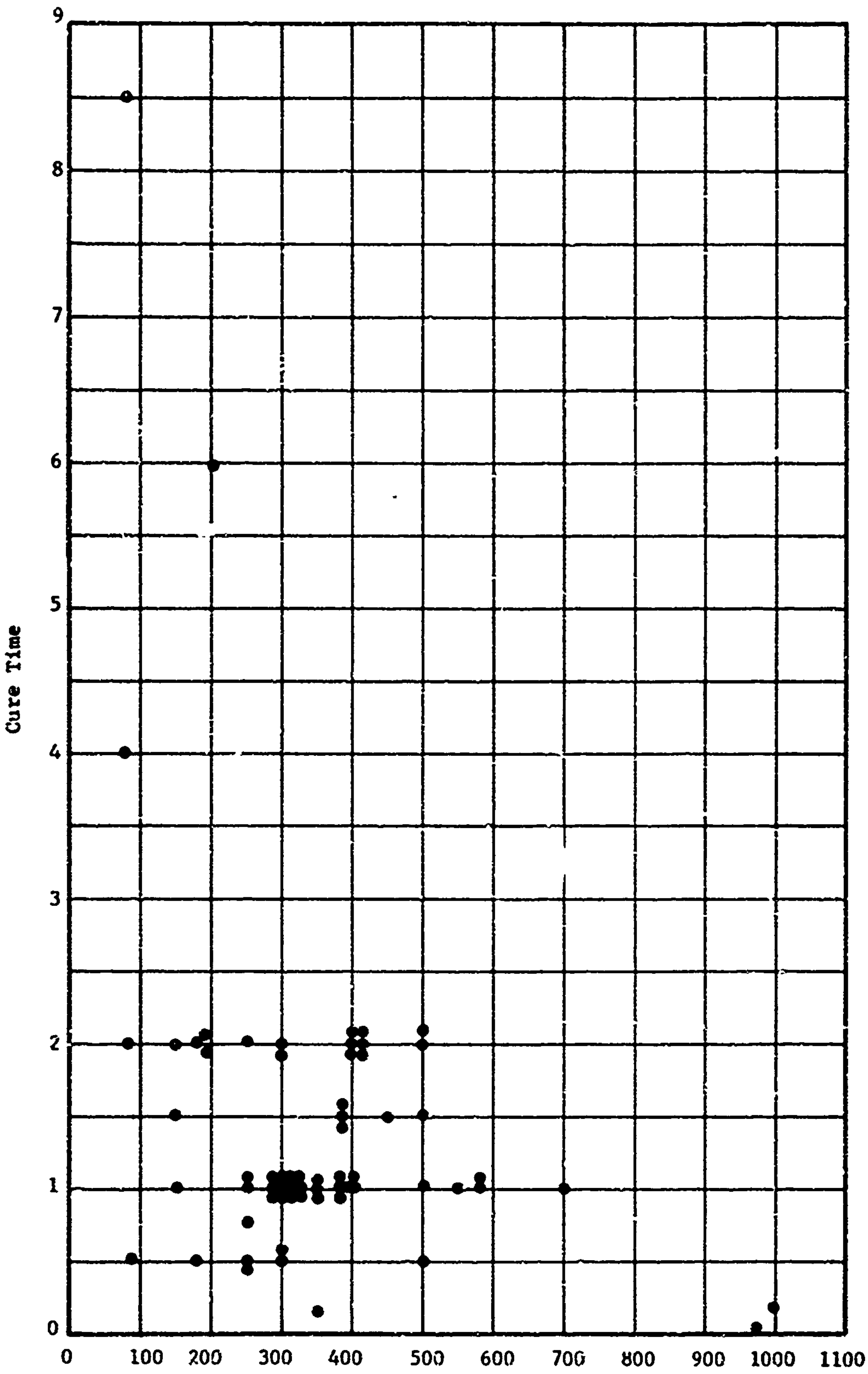



Fig. 2 Cure Time and Temperature for 63 Solid Film Lubricants

shorter times may be used with the following restrictions:

- A shorter wear life will result which may not be acceptable for critical applications
- Higher temperature cures cannot be used with aluminum and magnesium
- Temperatures above 500$^{\circ}$ F should not be used
- Certain solid film lubricants cannot be cured at such temperatures and would be either eliminated from the QPL or cured at lower temperatures

Actually, many of the paint shops have, under the pressure of production, done essentially this. The problem is that it is doubtful if they have considered the above restrictions. Although only two cases were noted (aluminum alloys cured at temperatures greater than 400) this could be serious in certain applications. A more rigorous investigation should be made of the solid lubricants used at the NARFS to see what changes could be made to consolidate the cures. This would require considerable input from the vendors since, in many cases, they alone know the composition of the resins.

J. Aerosol Sprays

Aerosol spray cans were found to be used rather extensively throughout the NARFS. Although they represent a major saving in manhours over the heat cured films there are inherent dangers in thei- . There is an even greater tendency to eliminate necessary pretreatment steps. Although the films are equal to the heat-cured films in potential wear life, in reality they turn out to be much poorer because of the poor processing. No general assessment was made of this form of film application, however, two examples were found where poor service could be attributed to faulty processing.

Whether this is typical or not is not impor- nt. The use of aerosol solid lubricant processing is a reality at the NARFS and would be almost impossible to eliminate since spray cans are available from stock. They also represent an appreciable saving in manhours and the movement of parts. In order to take

advantage of this saving some method must be devised for insuring the correct application of the films. Preparation of an instruction is not the solution since experience has shown that very little attention is given to such things in practice. It would seem more advisable to develop a kit or standard inexpensive facility for aerosol applications. It should contain means to surface roughen, clean, and apply the solid lubricant. Such a facility would be available to a shop which had sufficient usage to justify it. This has advantages other than manhour savings. By applying their own films the shop itself would see the consequences of poor processing and would act accordingly.

K. Quality Assurance

At the present time the NARFS use only a visual inspection to determine the quality of solid film lubricant coatings. An improved program in this area would undoubtedly improve the processing discussed previously. The military specifications are quite detailed on the subject of quality assurance. Actually the only sure test is a wear test which is frequently used in industry to check the quality of the coating. However, this would necessitate setting up and operating wear tests which are impractical at the NARFS. Two very simple tests are used in the specifications, which can be used at the NARFS; these are the tape adhesion test and a film thickness measurement. It is a simple matter to check the thickness before and after coating. It is recommended that these tests be instituted as quickly as possible.

L. Summary - Processing

It can be seen that many improvements can be made in the processing of solid lubricants. In most cases, these improvements do not involve significant additional manhours and would appreciably increase the service performance of the lubricant film. They would also prevent premature part failures and high part replacement in applications where the wear life is critical. Several direct examples where failures can be attributed to improper processing have been found.

- Engine Starter Valve A/N 109632-6

This high temperature valve controls the air flow to the engine. It

is essentially a pipe body (PN 118431-1) and a butterfly (94755-40-7-1-AG). The body is coated with Electrofilm 4396 and cured 1 1/2 hours at 325° F. The coating process was observed and it was apparent that the coating was being applied too thick. A visit to the originating shop indicated that upon reassembly the butterfly would not turn in the body. They adopted the practice of spraying the coating with Moly Kote 321 to loosen up the butterfly. Inspection of used parts indicated that the film is always worn off in service and there is damage to both the body and the butterfly. The butterfly is almost always replaced. They have been using this process for many years but only have had problems in the last 8 months. The same problem is noted on other valves (e.g. 36E45-1). The film on a returning valve could be flaked off easily and its film thickness was measured to be .0024" to .0030". This is about ten times too thick and would explain both the initial binding and the poor life. The solvent in the Moly Kote 321 probably softened the coating to allow it to wear in.

- Compressor Blades

At one facility an unqualified product as specified in the manual was used on the compressor blades. It was observed that the resulting product was easily scratched. The reason for this behavior could not be precisely determined but no pretreatments were used and the cure (475 F) was high. Occasional galling of the blades was noted which could lead to early fatigue failures.

- Bomb Racks

In one ordnance shop the engineering specification requires that most of the moving parts be coated in accordance with a local process specification which outlines the process correctly and refers to MIL-L-8937. The resulting product purchased under this specification was of the type which had to be thinned (therefore, not a qualified material). This was applied with no pretreatments except a solvent wipe and most parts were coated by brushing. Inspection of returning racks indicated

that most of the coatings were worn through and many of the surfaces were galled. This damage could be removed by buffing and the parts reused and recoated, however this operation is unnecessary; the coating should have been intact. Furthermore, the galling could cause a malfunction of the rack.

- Pilot Harness Inertial Reels

  These reels hold the belts which hold the pilot against high G forces. They are presently being relubricated with an aerosol spray and given an improper cure. In service, this film is flaking off and locking up the reels. <u>The locking of the reels causes a personal hazzard to the pilot</u>. With improved film application this flaking should not take place. For a critical application such as this, a lubricant conforming to MIL-L-8937 should be used.

- Butterfly Valve Gear

  The solid lubricant film applied to a gear rack comes of the rack in service. Although the precise cause of this could not be determined the film is applied at a facility which it was noted does apply coatings which are too thick.

These examples are not given as criticism of any facility but only to illustrate the consequences of improper application techniques. Actually more solid lubricated parts which were seen as they were returned from service had the film worn through but were undamaged. In the above cases, damage could be attributed directly to the processing.

Actually, it is surprising that many more examples were not found. This may be due to the fact that when such problems are found, the solid lubricant is blamed and a grease or oil is substituted. However, a far more probable reason is that many of the applications only experience a few sliding cycles of operation during their lifetime and almost any film or film application technique would suffice. However, this does not justify poor application techniques. It does, however, suggest that some parts are receiving unnecessary treatments

and considerable saving could be realized if these treatments were eliminated. These decisions cannot be made by the sprayer, however since it requires knowledge of loads, temperatures, and sliding cycles (among other things).

Many steps could be taken to establish the ideal in film processing that exists in the laboratory situation. However, the visits to the NARFS have shown that many of the requirements and traditions established by the industry are necessary only in a minority of applications and in fact are almost impossible to achieve in practice. Thus, as always, the correct course of action lies somewhere between the two extremes. It is felt that certain steps must be taken in film processing to prevent service failures such as those cited and certain other steps could be taken to improve the performance of solid films. With the improved performance, it is possible that the present applications could last several tours of duty or even the life of the plane. Such and eventuality would save many manhours of rework time.

Some action should be taken to insure that all the parts coated with a solid lubricant film are clean, have received some surface roughening treatment, and are coated to a thickness of .0002 to .0005 in. To accomplish this, the following are recommended:

- A training program should be established in aircraft lubrication maintenance specifically concerned with solid lubricant materials and processes. A course should be given and its content directed toward aircraft maintenance personnel. The course content should instruct in the proper step by step, application of the solid films and the consequences of deviation from this procedure.
- A quality assurance program should be instituted on a random sample basis to measure the film adhesion and the film thickness of coated parts. The tests outlined in MIL-L-8937 should be used as a guide.

It is felt that these two steps will resolve many of the associated problems of film application. The technical manual previously discussed would also contribute significantly since it would not only discuss the films but also outline in detail the technical details of the film processing steps and

institute the new technology for improved performance, outline standardization and centralization of facilities, and outline some of the unresolved practices such as film stripping and touch up. However, the greatest impact of the manual will be to point out those applications where selective pretreatments could be eliminated to save maintenance hours and to outline techniques to select such applications.

Other recommendations for improved lubricant performance are as follows:

- Instructions for film application should be placed upon the containers.
- A study should be made to assess the possibility of using a single cure (temperature and time) for most solid lubricants.
- A single facility with a limited number of operators should be designated to put on special coatings which require greater precision of application than paints.

M. Handling

The importance of cleanliness in the application of solid film lubricants has previously been discussed. Once the film has been applied it is also necessary to apply some general rules of cleanliness. It has been found that contamination of the surface with dirt or oil or other fluids is harmful if it remains on the surface during the sliding cycle. However, if it is removed before use little harm will result.

During this survey it was found that once the parts were coated almost no precautions were taken to prevent surface contamination. Coated parts were transported in baskets which are open to the atmosphere, they are often stored in trays or bins with used or oiled parts, and handled by hand. Most important, however, is the fact that the practice of applying a coating of light oil to the parts is widespread. This can shorten the life drastically.

This is a difficult situation to correct since coatings are usually applied to parts for which special handling is usually not required. Secondly, if solid

lubricants are ultra sensitive to handling they probably should not be used in these practical situations. Nevertheless, almost all mechanics and certainly the NARFS use elaborate precautions, clean rooms, white cloaks, etc. in the handling of rolling contact bearings. Therefore, some systems for insuring coating integrity is not asking too much. At least the parts should be tagged with a warning that they should be kept clean, free of dirt and not oil lubricated. The best solution would be to provide 4 mil polyethylene bags to the sprayer. Small parts could then be sealed in this bag along with the warning tag. Such a practice would be impractical for blades or large parts but these are usually handled in racks so the problem is not so acute.

In the future as less sensitive films are developed this precaution may be eliminated.

## VI. GENERAL PROBLEM AREAS

### A. Introduction

An attempt was made to learn the problems concerning solid lubrication of actual hardware. This necessitated visits to actual Naval Air Rework Facility shop areas (e.g., landing gear shop, wing shop, hydraulics shop, etc.) and discussions with shop foremen and individual workmen. Shop personnel recognizing the objectives of the program would point out parts with high usage or other difficulties. Discussions with aircraft project engineers and materials engineers would allow these problems to be put into an expanded perspective.

While the intent of the investigating was to learn about the performance and practices concerning solid lubrication, the actual discussions with pertinent personnel necessarily developed information about non-solid lubricated rubbing systems having difficulties. Some of these are potential new solid lubricant application areas, but many were not. As this latter information is also of value, it has been included here.

In trying to give help with particular problems, information was not usually available nor readily obtainable concerning a parts operating condition, that is load, operating speed, frequency of operation, and the like; it must be borne in mind that some of these parts could have been designed or gone out of production two decades ago. Although the examination of the systems could therefore be only superficial, an attempt was made to recommend the best that could be recommended based on an expert knowledge of the field and much practical experience.

In time all things must wear. The question really boils down to questioning whether the rate of wear is reasonable or not. Too often we take for granted that wear will occur and accept an unduly high wear rate, as a natural event. It is with this perspective that flight hardware was examined.

### B. Landing Gear

The landing gear received emphasis as a possible problem area, because it

represents a critical aircraft sub system, is likely to see much use, and is exposed to hostile conditions (open to atmosphere, closest to ground, etc.). Numerous problems were found, and many of them had generality, that is, were found in many different types of aircraft and designs. The first of these general major problems to be discussed is the aircraft brake disk pack problem.

### 1. Aircraft Brake Disk System

Multiple disk aircraft brakes usually have a sequence of internally and externally splined disks, or in older designs, externally splined disks and calipers. The kinetic energy of the aircraft is absorbed by the sliding friction of disk face contact, and the brakes are designed and developed with that consideration in mind. A second type of rubbing surface exists however, the spline on which the disks are axially mounted and allowed to move. In examining brake design after brake design, it became clear that this second rubbing area can be of critical importance, yet is usually ignored. Dry metal-to-metal sliding in the spline area, that is unlubricated sliding, was found to have three possible major consequences:

- Spline friction greatly reduces the load transmission through a multiple disk pack, that is the load drops off from the front to the back of the pack due to friction, with the consequence that brake performance is seriously degraded (i.e., the brake cannot develop its theoretical energy absorbtion). The disks near the loading end see higher loads and temperatures and therefore prematurely wear or fail.
- The rubbing action of the spline and disk tang areas causes excessive wear of those areas with the result that disks or keys are scrapped prematurely for being out of geometrical tolerance.
- Dry metal-to-metal contact has a high coefficient of friction, thereby inducing significant frictional bending moments on the disks. These moments attempt to dish and warp the disks, adding to the problem of thermal stress induced moments which have the same effect. This dishing and warping degrades system performance,

and leads to much rework; a great deal of time is spent pounding out the dishing trying to get the surfaces flat again.

The aircraft most noticeably suffering from one or more of the above spline friction induced problems are the A7, A4E, P3B, A6, F4B, and F4J; these problems are summarized in Table 10.

TABLE 10

LANDING GEAR BRAKE SPLINE RUBBING PROBLEM

CONSEQUENCES:

1. Reduced performance
2. Excessive wear and resulting parts usage
3. Friction moments which deform disks

AIRCRAFT EFFECTED

A4, A6, A7, F4B, F4J, P3B

The specific problems on each aircraft's brake are detailed in Table 11. These problems can be solved, or at least greatly lessened, simply and cheaply, by coating the spline areas of the enumerated brake parts in Table 11 with a high temperature bonded solid lubricant film, say MIL-L-81329A.

The presence of a solid lubricant film on the disk spline surfaces would probably significantly reduce the scrappage of parts for being out of dimensional tolerance in the spline area, as the wear rate would drop by orders of magnitude. The lubricant film would also lower the coefficient of friction at the spline contact thereby helping to alleviate the friction moment dishing and warping problem, and the uneven load transmission problem.

TABLE 11

SPECIFIC AIRCRAFT LANDING GEAR BRAKE PROBLEMS IN SPLINE AREAS

A7:

1. Rotating discs (PN 9542898; FSN IRM-1630-991-4325 GA) are short-lived due to excessive spline friction moment induced lining cracking. As a result, Alameda alone, in the past 6 months used 274; Navy wide usage has been 3591 in the past 12 months and 1660 in the last 6 months.

2. Stationary discs (PN 9534357; FSN IRM-1630-991-4319-GA), of which Alameda alone used 65, would last longer if splines were lubricated; Navy wide usage has been 3741 in the past 12 months and 2442 in the past 6 months.

3. Key disc drives (PN 9536635; FSN IRM-1630-809-2641-GA), which are the mating part to the rotating discs, have excessive wear. As a result, Alameda alone in six months used 110; Navy wide usage has been 1176 in the past 12 months and 392 in the last 6 months.

A4E:

4. Brake disc (PN 9531709; FSN 1R-1630-524-2600-DA) has excessive spline wear and consequent parts replacement. As a result Alameda alone, in six months, used 314. Navy wide usage has been 4183 in the last 12 months and 1791 in the last 6 months.

P3B:

5. The steel brake disc (PN 133-255; FSN IRM-1630-998-7937-BP) undergoes rework because of dishing. The rework involves pounding the disc flat with a hydraulic hammer. This dishing is caused by a combination of thermal stress and the spline friction twisting moment. This moment can be relieved by solid filming the spline area of the disc. These discs have an excessive rework problem rather than a discard problem. Even so, Navy usage in the last 12 months has been 329 and in the last 6 months 165.

TABLE 11 (Continued)

6. The rotating disc (PN 244-212; FSN 1R-1630-998-7936) has spline wear and face chipping. Alameda alone in a six month p[illegible] used 102; Navy wide usage in the last 12 months has been 796 and in the last 6 months 414.

A6:

7. Rotating discs (PN 9532757) have wear in spline area, and when the tangs fail to meet the limits of a go no-go gage are discarded.

8. Stationary discs (PN 9532756) also have spline area wear.

F4B and F4J:

9. Rotating di[illegible]s (F4B, PN AP 313590; F4J, PN AP 320545) show more than 3 mils wear on the tangs exceeding the permissible limits of go no-go gages.

10. Stationary discs (F4B, PN AP 313591; F4J, PN 320546) also show excessive spline area wear.

11. Spider Assembly (F4B, PN AS 216339; F4J, PN AP 320561) which mates to stationary discs also suffers from wear in the spline area.

The lubricant must be a bonded high temperature solid film properly applied. Care must be taken to insure that this is actually done, and an aerosol air drying film is not substituted in its place at some time in the future. This point is being stressed in view of current experience with the S2A, C1A. The Wear Adjuster-Pin Assembly (PN 147633; FSN RM-1630-041-4909-XX6X) on the brakes for these aircraft is made of brass and is lubricated with an aerosol air drying solid film lubricant prior to assembly. This lubricant cannot stand the rigors of the aircraft brake environment. Its inadequacy is indicated by Quonset Point's usage, due to wear alone, of 622 in the last 6 months.

The recommended solution to the pin adjuster problem discussed above, is to coat the surfaces with extreme environment solid film lubricant, MIL-L-81329A, using proper cleaning, pretreatment, and curing procedures.

## 2. Brake Hydraulic Actuation System

The second general landing gear problem area is in the aircraft brake hydraulic actuation system. Usually the brake cylinder is not a separate component, rather it is machined into a housing or end plate, usually an expensive and complex forging made of aluminum or magnesium. A housing may have from 3 to 8 pistons and cylinders, depending on the design. The pistons are usually made of anodized aluminum.

At present, excessive wear occurs either on the piston, the bore or both. This wear leads to

- Excessive leakage in operation, seriously degrading performance and necessitating rework.
- Excessive rework labor hours.
- Excessive parts usage and scrappage.

The aircraft most noticeably suffering from this problem are the A3, A4, A6, A7, F8, S2A-C1A, S2B-E1B, H2, and H3. The specific problems on each of these aircraft are detailed in Table 12.

## TABLE 12

## AIRCRAFT LANDING GEAR BRAKE PROBLEMS ARISING IN THE HYDRAULIC ACTUATION SYSTEM

1. A4 Landing Gear Brake: Abrasion of Brake Housing and Brake Pistons - Dirt between the anodized aluminum brake piston (PN 9523532; FSN IRM-1630-586-1368-DA) and housing (PN 9560348) causes significant wear of the two. This requires replacement of many standard pistons, and when the condition is severe enough, which is often, the reboring and reworking of the housing to accept an oversize piston (PN 9523975; FSN IRM-1630-717-1170-DA). The next step is to discard the whole brake and this is done about every second rework, at Pensacola. To give some idea of the magnitude of the problem, Alameda alone in the last 6 months replaced 62 standard size pistons and used 36 over-size pistons; Navy wide usage in the last 12 months is 312 standard pistons and 1664 over-sized pistons, and in the last 6 months 176 standard size pistons and 1014 over-sized pistons.

2. A3 Landing Gear Brake Housing: Adhesive Wear - The rubbing action of the brake piston against the cylinder wall of the housing (PN 9532267; FSN IRM-1630-776-0740-BA), causes excessive wear. This is sometimes remedied by housing rework and the substitution of oversize pistons (PN 9531676), but housings ultimately have to be scrpped; Navy usage has been 26 housings and 157 oversize pistons in the last 12 months.

3. S2A, C1A Landing Gear Brake: Wear of Piston and Housing - The brake piston consists of a large diameter anodized aluminum annular ring (PN 148143), moving in an annular groove in the housing (PN 15196). As in other brake systems, wear is an important problem. In the last 8 months, Quonset Point bought 30 pistons. It is not clearly understood whether the wear is of the adhesive type, resulting from the surface contact of the two parts, or of the abrasive type, arising from dirt (possibly contaminants in the hydraulic fluid).

TABLE 12 (Continued)

4. H3 Rotor Brake: Caliper Housing Wear - Excessive wear of the anodized aluminum caliper housing (PN 9440345; FSN RH-1630-874-7274-OH7x) promotes corrosion and leads to significant rework with reboring to accept oversize pistons, and actual caliper discards. In the past 6 months Quonset Point used 50 oversize pistons (PN CHR9429494; FSN RS-1630-633-632-6H6x) and 2 caliper housings.

5. H2 Rotor Brake: Caliper Housing Wear - Excessive wear of the anodized aluminum caliper housing is occurring in a manner identical to that on the H3 Rotor Brake. Considerable rework is occurring and Quonset Point has had to discard 3 caliper housings (PN 9440998; FSN RH-1130-178-8534-BH7x) in the past 6 months as beyond rework.

6. A7 Landing Gear Brake: Wear of Pistons and Housing - The rubbing of the brake actuating piston (PN 9534473) in its cylinder (PN 9535849) causes wear and rejection of t[illegible]n this multiple disc system; this was considered a major problem at Jac[illegible]ille.

7. E1B, S2B Brake Piston - Excessive wear is occurring on the brake actuator piston (PN 151092).

8. F8 Landing Gear Brake - This is an essentially caliper style brake system. Excessive wear of the magnesium actuating cylinder housing (PN 9540859) necessitates use of oversize pistons (PN 9522608) and later on sleeves and regular size pistons (PN 9522166), both of which also show wear.

9. A6 Landing Gear Brake - The actuating hydraulic system in this multiple disc system consists of eight pistons (PN 9524582) in cavities in a housing (PN-9525238). Due to wear in the cylinder region, pistons, the housing, or the whole assembly (PN 9560538) have to be discarded. This is a common occurrence at Norfolk.

The wear itself may differ in cause. In some systems it appears to be abrasion resulting from contaminant particles. In other systems it appears to be adhesive wear resulting from the rubbing of the piston and cylinder. In still others it appears to be a combination of the two.

The very number of brake types having these problems has several possible implications:

- A feed-back loop to aircraft brake designers does not exist, and they are unaware that they keep designing (usually by materials selection) the same problem into new designs.
- Governmental purchase and design specifications, to which aircraft brakes are designed, contribute to the recurrence of this problem, possibly through omission of requirements.

In commercial non-naval rework, hydraulic and sliding components are routinely coated with wear resistant materials. Perhaps these parts can be salvaged in a similar manner. For example, Union Carbide Coating Service reworks the Boeing 707 and 727 tail stabilizer cylinder by plasma spraying it with aluminum bronze. They rework C-141 main landing gear cylinders by applying chrome oxide; these are proof tested to 3500 psi. Hohman Plating and Manufacturing chrome oxide coats non-aircraft hydraulic cylinders which withstand pressures of 35,000 psi. These organizations have also successfully used plasma sprayed plasma nickel and tungsten carbide in non-aircraft applications.

A program is needed by NAVAIRSYSCOM to evaluate the possible means of controlling brake system piston-cylinder wear problems with a plan based on the use of actual hardware in order to provide a solution. This program should consider materials and processes.

It is estimated that possible candidate materials to be considered for application to the surface of these parts could include:

Aluminum bronze

| | |
|---|---|
| Chrome oxide | 400 Series stainless steel |
| Plasma nickel | Cobalt alloys |
| Cemented tungsten carbide | PTFE filled hard anodize |
| Molybdenum | Soft metal platings |

Some of the application processes which could be considered include:

Plasma spraying
Wire spraying
Plating
Anodizing

A survey should be made to determine which materials and processes are likely to give both adhesive wear and abrasive wear resistance. Candidates should also satisfy the requirement that they are implementable with the NARFS present equipment and facilities.

Actual brake hardware should be used in a test program to establish which of the materials and processes candidates, firstly, will actually work, and secondly, be simple to implement at NARFS. The results of this testing should be applicable to actual flight hardware.

### 3. Landing Gear Bushings

A third general problem area is that of landing gear bushings. Standard practice at Bendix and others has been to design steel bushings mating with chromium plated pins, or in cases of almost no motion, cadmium plated steel pins. These bearing systems receive virtually no lubrication except at rework. The dry sliding of chromium plated steel on steel (and possibly steel on steel) seems inherently trouble-prone.

On newer aircraft designs, Bendix has shifted to a preference for aluminum bronze bushings in preference to steel bushings. But this substitution has not found its way into the rework of current naval aircraft. Boeing, as a weight savings, has adopted aluminum bronze coated aluminum bushings for the 707, 727, 737, and 747 commerical aircraft (provided by Union Carbide

Coating Service).

Robins AFB experienced trouble with the steel bushings in the C-141, and changed to grease lubricated bronze (possibly aluminum bronze) bushings with satisfactory results; as an example, the bushings on the C-141 lower torque arm (PN-3G1-0008).

Two of the aircraft presently suffering from the steel bushing problem are the S2D and A6. The S2D has steel main landing gear bushings (PN QP30990-2; QP31056-1,2,3). They may or may not have a grease fitting which may or may not be used. Most steel bushings are damaged in service, requiring about 60% replacement. Usually, these must be made in-house since they cannot be purchased. In most instances the bearing is only lubricated upon re-assembly. The cost of disassembly and assembly is quite high. For the two types of bushings mentioned above, Quonset Point in the last six months, has had to manufacture 40 of the first type and 20 of the second type. The A6 main landing gear spring arm (PN 9937A-73B) contains many steel bushings. These presently constitute a troublesome situation at Norfolk.

The real question these examples raise is why steel bushings? Why even aluminum bronze? While the latter would constitute in view of the above information, a considerable improvement, still better materials are available and should be explored. In recent years considerable progress has been made in the development of composite materials and in the development of surface damage resistant coatings. If suitable materials are selected from these classes of materials, then the reliability of lubrication would no longer constitute a question, and the operating interval could be extended. Some of the composite materials which could be considered are the sintered metallic-solid lubricant types (Molalloy's made by Pure Carbon Co.) and the filled polyimides (made by several manufacturers). The composite materials would provide their own lubrication, thereby reducing maintenance in the fleet, and with their low wear rates and high surface damage resistance, would allow extension of the operating interval. A study should be made to see which such materials can be substituted for the present steel bushings.

4. Parts Usage

To gain insight into problems being experienced in the field, in contrast to those observed at the NARF's, the Aviation Supply Office (ASO) was requested to give parts usage for selected landing gear parts, for 12 month and 6 month periods corresponding to the same period for which parts usage was determined for Alameda NARF. The results are given in Table 13.

It must be borne in mind, when examining these figures, that more than one NARF works on a particular type of aircraft. Even so, an examination of the magnitude of these numbers raises some interesting questions, and makes some interesting points.

The A7 key disk drive usage, which results almost entirely from the spline friction problem, shows the importance and currentness of the problem.

The large number of A7 disks replaced in the field, compared to the NARFS, realizing that replacing a disk entails the virtual rework of the brake system, suggests that more rework may be going on in the field than at the NARFS. A further breakdown by ASO of where these disks were actually sent, reinforces the impression.

The A4E oversized piston consumption, is even more suggestive that much rework is going on in the fleet.

This matter may warrant further attention in order to adequately evaluate its significance.

C. Hydraulics and Pneumatics

Hydraulics and pneumatics shops were visited at Naval Air Rework Facilities to learn the problems they were encountering with hardware. Discussions were held with NARF engineers, as well as engineers at commercial firms involved with hydraulic systems, including Bendix, Lockheed-Marietta, Union Carbide Coating Service, and Hohman Plating and Mfg. Company. It was found that most hydraulic cylinders and piston systems consisted of the following material combinations:

TABLE 13

AIRCRAFT BRAKE PART USAGE

| Aircraft | Part | Cost Per Part | Alameda 6 Month Usage | Total Naval Air Usage 6 Month | Total Naval Air Usage 12 Month |
|---|---|---|---|---|---|
| A7 | Key Disk Drive | $ 2.90 | 110 | 392 | 1176 |
| A7 | Rotating Disk | 73.00 | 274 | 1660 | 3591 |
| A7 | Stationary Disk | 63.00 | 65 | 2442 | 3741 |
| A3 | Housing | 150.00 | 2 | 2 | 26 |
| A3 | Oversized Piston | 8.00 | 10 | 20 | 157 |
| A3 | Lining | 2.60 | 408 | 2517 | 7152 |
| A3 | Steel Rotor Disk | 89.00 | 10 | 18 | 106 |
| A4E | Oversized Piston | 5.30 | 36 | 1014 | 1664 |
| A4E | Piston | 3.30 | 62 | 176 | 312 |
| A4E | Disk | 40.82 | 314 | 1791 | 4183 |
| A4E | Lining (square) | 1.90 | 155 | 17285 | 49957 |
| A4E | Lining (round) | 2.40 | 557 | 10993 | 23243 |
| P3B | Rotating Disk | 41.00 | 102 | 414 | 796 |
| P3B | Stationary Disk | 60.00 | 0 | 165 | 329 |
| P3B | Pressure Plate | 85.00 | 0 | [illegible] | 129 |

- Chrome plated steel piston and anodized aluminum cylinder
- Chrome plated steel piston and steel cylinder
- Anodized aluminum piston and chrome plated steel cylinder
- Steel piston and chrome plated steel cylinder
- Anodized aluminum piston and anodized aluminum cylinder
- Steel piston and steel cylinder

Therefore the materials universe of hydraulic components, as seen in practice, is restricted to aluminum. steel and chromium plating. This is sometimes justified on the basis of the following military specifications:

- MIL-C-5503C (27 June 1963) - General Requirements for Aeronuatical Hydraulic Actuating Cylinders.
- MIL-C-5503C Amendment 3 (22 December 1969)
- MIL-H-8775C (8 January 1964) - General Specifications for Aircraft and Missiles Hydraulic Systems Components.
- MIL-L-8552C (19 November 1965) - Military Specification Landing Gear Aircraft Shock Absorber (Air-Oil Type).
- MIL-L-8552C Amendment 2 (10 December 1968)

Careful reading of these specifications shows that hydraulic components are not actually limited to these materials combinations; other materials may be used if they can be justified with test data. Also, MIL-C-5503C actually forbids use of aluminum pistons (where the aluminum would be the bearing surface). Table 14 lists and discusses 16 current problems found on the hydraulic and pneumatic systems of the A3, A6, F4, F8, H3, and P3A. Other aircraft are not listed simply because they did not receive as much attention in this area; very likely more careful examination of other aircraft would reveal a substantial number of additional and related problems.

1. Wear and Damage

The major problem in hydraulic components is damage or wear of aluminum

## TABLE 14

### CURRENT PROBLEMS WITH AIRCRAFT HYDRAULIC AND PNEUMATIC COMPONENTS

1. A3 Fin Fold Actuating Cylinder - The anodized aluminum barrel is scored by dirt, requiring replacement.

2. H3 Main Landing Gear Strut Floating Piston - The main oil to air piston (PN S6125-50117) is made of anodized aluminum and moves in a steel cylinder. The wear of the piston leads to excessive leakage and thereby constitutes a major problem at Quonset Point.

3. A6 Nose Landing Gear Hydraulic Cylinder System - The chrome plated piston develops pits and damage in service and these are buffed out if possible.

4. A6 Canopy Actuating Cylinder - A steel piston rides in a chromium plated steel bore (PN 128HM10157-1). Abrasive gets between them causing deep scratches. This usually is treated by stripping the chrome plate, plating, and honing. About 30% of the cylinders at Norfolk receive this processing.

5. A6 Electrohydraulic Rudder Servo Pack End Cap (for rudder) (PN 19899) - A steel shaft rubbing on the aluminum end cap, galls the cap. When the wear is 2 mils the part is discarded. At Norfolk, 95% of these end caps have shown this problem.

6. A6 Flaperon Cylinder Assembly End Cap (PN 19614) - A steel shaft rubbing on aluminum end cap galls the cap. 75% parts replacement at rework is now occurring. A local temporary fix at Norfolk is the use of a bronze bushing.

7. F8 Hydraulic Barrel (PN 615741?C; 601 401-1LH; 601 401-2RH) - This aluminum cylinder sees the motion of a very long chrome plated steel piston. The barrel is supported by a strap near its middle which tends to distort it out of round, with consequent wear near the middle region. This wear causes dimensional tolerances to be exceeded, and the part is scrapped. At Norfolk 75% of these parts are discarded.

8. F8U Wing Fold Poppet Valve - It is very difficult to get a new valve to properly seat, and it may require the installation of five or six before this properly occurs.

TABLE 14 (Continued)

9. F8 Main Landing Gear Cylinder Cap Assembly (PN 601422-101) - Pitting corrosion may be seen over large surface areas. These parts are reused, pits and all.

10. A6 Ram Air Turbine Actuating Cylinder Head Fitting (PN 128HM10336-1) - Extensive internal pitting occurs but the part is reused with them; no replacements are available.

11. P3A Power Brake Valve Slide and Sleeve Assembly (PN 18066; FSN RM-1630-821-4686Y120) - Wear on the surfaces of these hard lapped servo control valves increases leakage until it exceeds an allowed maximum at which point the parts are discarded.

12. F8U Dive Brake Selector Valve Slide and Sleeve Assembly (PN 15424) - Wear on these lapped to match servo control parts results in excessive leakage at which point the parts are scrapped.

13. P3A Hydraulic Dual Brake Valve Lever (PN 15929) - A steel roller is mounted snugly on a steel pin. Wear of these steel surfaces, immersed in hydraulic fluid, results in 60% parts replacement at rework.

14. F4 Gas Turbine Starter Engine Pneumacic Bleed Valve (PN 109632-6) - Has a binding and possibly excessive parts wear problem (PN 118431-1, 94755-40-7-1-AG) due to excessive bonded solid film thickness (2-1/2 to 3 mils, ten times too much).

15. P3A Pneumatic Valve Starter Control (PN 38E45-1) - Binding of parts due to excessive solid lubricant film thickness.

16. F4 Flap Valve Gear Rack (PN 626415; 626121) - This mechanically actuated valve has experienced excessive gear rack wear due to inadequacy of applied solid film lubricant to protect surfaces. This may be a problem of processing technique rather than of materials per se.

or chrome plate, and the consequent scrappage or expensive rework of the parts. These problems are inherent with these materials, and perhaps the time has come for us to go beyond chrome plate and/or aluminum to surface materials with inherently greater damage and wear resistance. From discussions with individuals of firms either designing or choosing aircraft hydraulic systems, it seems clear that they are unaware of the problems with current materials combinations, and in fact, are quite content with them. An information feedback loop seems to be missing.

Items 1, 2, 5, 6 and 7 in Table 14 relate to the damage propensity of the aluminum surface. Item 7, the F8 hydraulic barrel (PN 6157411C; 601401-1LH, 601401-2RH), is a long aluminum hydraulic cylinder supported near its middle by a strap which slightly deforms it out of round. As the chrome plated piston moves back and forth it wears the aluminum at this spot. During rework the barrel is checked and found to be out of dimensional tolerance, and so is scrapped. 75% of the barrels are rejected at rework. Leaving design aside, the problem is the inadequate adhesive wear resistance of aluminum. Figure 3 is a photograph of the barrel.

Another example is item 2 in Table 14, the H3 main landing gear strut floating piston (PN S6125-50117). An anodized aluminum piston moves in a steel cylinder. Wear of the piston, possibly due to abrasive contamination of the hydraulic fluid, leads to excessive leakage. The problem here may be inadequate abrasive wear resistance by the aluminum. Another example of insufficient abrasion resistance to dirt is item 1, the A3 fin fold actuating cylinder.

Items 5 and 6, the A6 Electrohydraulic Rudder Servo Pack End Cap (PN 19899) and the A6 Flaperon Cylinder Assembly End Cap (PN 19614), both suffer from the same problem. A steel shaft rubs on an aluminum surface, causing galling of that surface, with a high percentage of present parts replacement. Figure 4 is a photograph of these parts.

Now let us look at an example of problems with the chrome plate, item 4, the A6 canopy actuating cylinder. A steel piston rides in a chromium plated

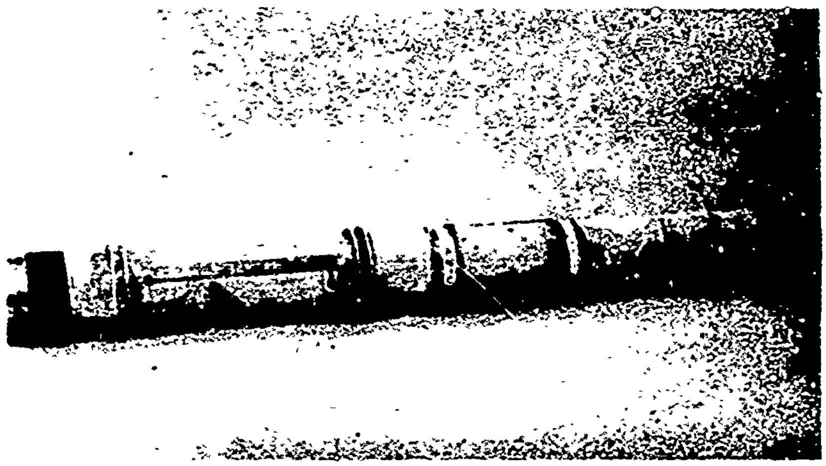
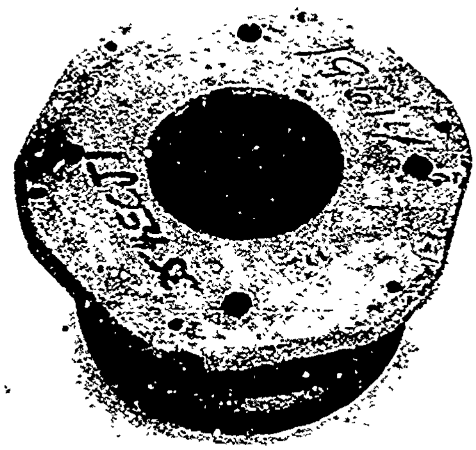


Fig. 3 F8 Hydraulic Cylinder Barrel which has 75% Replacement at Rework,





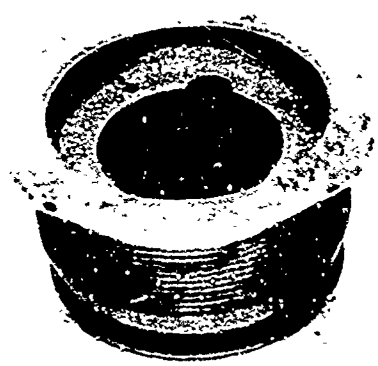


Fig. 4 A6 Electrohydraulic End Cap and A6 Flaperon Cylinder Assembly End Cap, Both Showing Wear and Surface Damage.

steel bore (PN 128HM10157-1). Abrasive gets between them causing deep scratches. This usually is treated by stripping the chrome plate, plating, and honing. About 30% of the cylinders receive this processing at rework.

Item 3, the A6 nose landing gear hydraulic cylinder is another example of the damage sensitivity of chrome plate.

Mildred Patterson at Alameda NARF has developed a simple alternative for the processing of chrome plated pistons or cylinders for use when the damaged or pitted area occupies no more than about 10% of the total surface area. The process consists of brush plating a nickel stroke on the surface followed by a nickel copper fill capped by nickel-tungsten or nickel-cobalt. This process is currently being used by the Air Force, but remains unused in many NARFS. At Robins AFB, use of this brush plating approach has reduced the rework time on the chrome plating of the C-141 main landing gear piston from three (3) weeks to four (4) hours. Inspection of those reworked parts after extensive service has shown no greater damage propensity on the brush plated areas than the remaining original chrome plated area. A considerable additional cost savings can be realized by reduction in the need for inventory of hydraulic components as rework can be accomplished in a few hours.

The general hydraulic cylinder wear and surface damage problem is similar to the landing gear brake hydraulic actuating system wear problem discussed in the last section, with the main difference being that more materials are used and the length to diameter ratio of bores can be considerably larger. The results of a program similar to that advocated there, to find a suitable salvage approach and materials, are urgently needed. Some of the possible surfacing materials which could be examined include the following:

- Aluminum bronze
- Chrome oxide
- Plasma nickel
- Cemented tungsten carbide
- Molybdenum
- 400 Series stainless steel
- Cobalt alloys
- PTFE filled hard anodize
- Soft metal platings

## 2. Quality Assurance in Purchased Parts

Now let us turn to other types of problems. Item 8, in Table 14, the F8U wing fold poppet valve and its failure to seat properly, points out the importance of having good quality assurance in parts purchase.

## 3. Corrosion

The F8 main landing gear cylinder cap assembly (PN 601422-101) and the A6 ram air turbine actuating cylinder heat fitting (PN 128HM10336-1), items 9 and 10 in Table 14 respectively, show a common problem — pitting in a hydraulic cap head. They point up our general impression that corrosion is the singularly most important problem facing naval aircraft and their subsystems.

## 4. Servo Control Valves

Hydraulic control valves are checked against leakage specifications of so many drops per minute. With time, normal wear occurs, increasing the valve leakage to an unacceptable level at which time the parts are presently discarded. Two typical examples are items 11 and 12 in Table 14, the F8U dive brake selector valve slide and sleeve assembly (PN 15424), and the P3A power brake valve slide and sleeve assembly (PN 18066; FSN RM-1630-821-4686Y120); Figure 5 is a photograph of these components. A publication by L.C. Horwedel ("Solid Lubricants as Organic Finishes," 47th Annual Technical Proceedings of the American Electroplates Society, 1960) discusses work which has shown that solid film coatings can be used on the surfaces of this type of component. In test hardware the coated surfaces were lapped to a 3 rms finish and successfully operated under 10,000 psi hydraulic pressure with no measurable leakage. This seems like a good way to reclaim components which are presently scrapped, and may in fact give better performance than the original valve.

The solid films which were found to work contained low melting point metal powders, which served to reduce the film porosity by melting at cure. The commerical product found successful in the test was Electrofilm 4253. Tests should be run on used valves, solid lubricated for salvage purposes, to

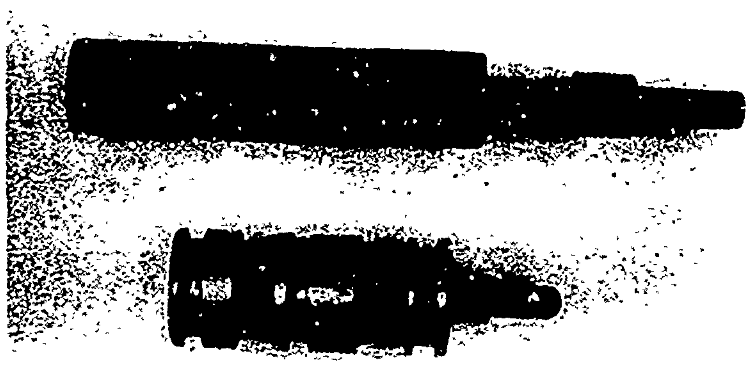




Fig. 5 Servo Control Valves from the F8U and P3A, which Might be Salvaged Using Bonded Solid Film Lubricants.

establish which product gives the best, or at least, successful operation, and thereupon this or these products should be adopted by the Naval Air Rework Facilities for use in conjunction with the salvage of servo control valves.

5. Wear Specification

P3A hydraulic dual brake valve level (PN 15929) item 13 in Table 14, is an example of either improper materials selection or treatment. A steel roller is mounted on a steel pin, and operates immersed in hydraulic fluid. In time wear occurs between the roller and pin, and the sloppy fit necessitates 60% parts replacement at rework. This problem which arises possibly out of improper heat treatment, or materials selection, points out a major problem — WEAR IS NOT NOW A MAJOR CONSIDERATION IN NAVAL AIRCRAFT DESIGN OR MATERIALS SPECIFICATION. Unless this is changed, future aircraft systems can be expected to have unduly reduced operating intervals and undersirably high rework costs.

6. Solid Lubricant Film Applications

Items 14 through 16 in Table 14, bring us back to solid film lubrication. F4 gas turbine starter engine bleed valve (PN 109632-6) and P3A valve starter control (PN-38E45-1), items 14 and 15 respectively, are pneumatic butterfly valves hindered in satisfactorily performing their operation due to excessive deposition of solid film lubricant. By actual measurement the film thickness was found to be 2.4-3 mils, about ten times too great. This points up the need for good parts processing and the necessity for quality assurance. This problem is discussed in greater detail elsewhere in this report. Item 16, the F4 flap valve gear rack (PN 626415; 626121) and its wear, is again a possible solid lubricants processing problem.

D. Seals

Leakage resulting from poor seal performance appears to be a major general problem in the operation of naval aircraft, and necessitates spending considerable rework time. The reasons for these seal failures include improper original seal design, improper materials selection, and faulty seal installation. Four

typical examples:

- F6 landing gear actuating piston O-ring seal
- F4J main landing gear hydraulic cylinder rubber piston ring.
- SH3-D servo cylinder in rotor head, excessive seal wear.
- F4 starter seal (carbon graphite).

Although many seals are replaced during aircraft rework, the replacement seals are usually made of the same materials and are of the same design as the original seals. None of the developments of recent years in improved seal materials, design, or installation techniques are utilized in seal replacement.

A study should be undertaken on the application of improved seal technology to naval airframes. This study should include the following tasks:

- An examination of the latest current developments in seal technology for the purpose of finding things utilizable in naval aircraft rework.
- An analysis of the specific seal problems existing on naval aircraft, and the state of their art.
- The making of specific recommendations as possible ares of improvement are revealed by the program.

## E. Wing Areas

In the wing there are many sliding surfaces which receive a variety of lubricants. The main areas are the following:

Roller guides - Tracks

Hinges

Wing Folds and Locks

Actuators

Rod End Bearings

Bellcrank Bushings

For the most part these are now grease or oil lubricated. The difficulty with this form of lubrication is that it is often neglected. Furthermore, the grease or oil attracts dirt which is retained on the surface; this causes accelerated abrasive wear of the surface. Although solid lubricants, either as greases or solid films, are not insensitive to dirt they do have some tolerance. Accordingly in many of these applications, where problems exist, it may be possible to substitute solid lubricants.

At each of the NARFS visited a tour was made of the wing shop to assess the condition of the above components upon completion of a duty tour. It was desired to learn if they experience galling or wear in service or if there was excessive parts usage. Usually the procedure followed was to point out each of the above components on the wing and ask the foreman or workman their condition upon disassembly. Using this procedure, the following information was collected.

1. Roller Guides - Tracks

On many aircraft the flaps and slats are mounted on tracks. When the flaps move, the tracks are guided by steel rollers. The tracks are usually steel but may be aluminum. In service the rollers "freeze up" due to dirt, corrosion, or lack of lubrication. The tracks then slide instead of roll and are worn excessively. Some examples where this has been found are the following. On the A-3, it is estimated that about 50% were frozen. This problem was solved by installing a grease fitting in the roller. Worn tracks are nickel plated to size and no lubricant is applied.

In a similar application on the A-3, the aileron actuator tube (P/N 5550143-1, -2) slides back and forth supported by a mechanism consisting of 3 rollers spaced 120°.(P/N 2432313). In service, many of the tubes are worn by the rollers. The manual (NAVAIR 01-40 ATA-2-2 Page 2-128K) states that the tubes require overhaul if the grooves exceed .010" depth. The present fix is to nickel plate back to size. Since the tubes are about 12' long, it is not a simple task. For an application such as this, the application of an aerosol solid lubricant spray may suffice to prevent this wear in service.

On the T-39 the flap tracks wear due to the seizing of the rollers. The problem is complicated by the fact that the tracks are no longer available and must be remade or repaired. This problem was further complicated by the fact that the manual specified Everlube (LB01040-001) which is a North American number and does not designate the lubricant. The present solution calls for nickel plating back to size and replacing the Everlube with a known lubricant presently applied at the facility. A similar problem has been reported on the A-4, however, it is felt by engineering that this was a problem of misalignment rather than one of lubrication. This may well be, but solid lubricants will compensate somewhat for misalignment and allow the heavier loads to be carried.

On the A6A flap track support rib a roller rolls (or slides) against an aluminum rib. Damage appears as pieces of metal flaked out of the aluminum. The current fix is to install, in rework, a metal insert of steel in the aluminum rib. This is a relatively simple solution which does not require much effort.

Thus, it can be seen that there are some problems in this area. Of course, it is desirable to keep the rollers free by inserting grease fittings, however, a solid lubricant, MIL-L-46010(A), could be added as a safety factor. This, in fact, is done in several aircraft.

## 2. Access Covers and Door Hinges

Hinges require frequent lubrication. Table 15 shows those areas of the F-4 which require, according to the manual, daily inspection and lubrication with general purpose oil every seven days. Figure 6 shows the maintenance card for the A-6 hinges and isolates 44 areas needing lubrication every seven days. Thirty-five minutes are required for each plane. This is not a great deal of time but it may not be necessary since this is a very natural application for solid film lubricants. Furthermore, it is the general feeling that in service many of these types of applications are neglected. This then causes excessive time being spent in rework to repair worn hinges.

TABLE 15

AREAS REQUIRING 7-DAY LUBRICATION OF F4 AIRCRAFT

Landing Gear Hinge Pin

Forward Missile Cavity Aft Door

Variable Ramp Mechanism Hinge Pins

Forward and Aft Cockpit Pressure Equal-Door Pins

Ram Air Turbine Hinge Pins

Arresting Hook Pins

Leading Edge Flaps Hinge Pins

Outboard L.E. Flap Hinge Pins

Wing Fold Hinge Pins

Ailerons Hinges

Spoilers

Trailing Edge Flaps

Speed Brake Hinge

| Card 31 | Time 00:35 | RTG AMS No. 1 | SPECIAL - 7 Days | Lubrication Hinges | Elec Pwr N/A<br>Hyd Pwr N/A |
|---|---|---|---|---|---|
| Task Min. | Work Area | Mos. No. 6341 | Publication Number NAVAIR 01-85ADA-6-3 | Card Set Date 15 August 1968 | Changed |

CONSUMABLE/REPLACEMENT PARTS

Lubricating Oil, General Purpose VV-L-800

NOTE: Clean all hinges prior to lubricating and clean area of excess oil upon completion.

| Task Min. | Work Area | |
|---|---|---|
| 35.0 | ALL | 1. Inspect and lubricate the following access covers and door hinges: |

a. Area 1 (forward equipments bay and nose landing gear doors).

b. Area 2 (30, 101, 102, 65, 59, 142, flaperon and left main landing gear and ram air tubine door).

c. Area 3 (192, 204, and arresting hook fairings).

d. Area 4 (30, 101, 102, 10, 177, flaperon, right main landing gear, and battery compartment doors).

e. Area 5 (30, 101, and 115).

f. Area 6 (113, 164 and handpump handle).

g. Area 7 (56, 108, 106, 105, 104 and boarding ladder hinge).

h. Area 8 (36, 27, 25A, 23, 21, 20, 19, 18, 17 and boarding ladder hinge).

Fig. 6 Areas Requiring Seven Day Lubrication on the A-6

In many facilities no problems were reported with hinges however several did. The F-8J droop hinges consists of a long aluminum hinge (approximately 8 feet) and a 1/8" diameter steel pin. Upon returning from a duty tour, it is noted that most squeak but far more important many are cracked and must be repaired. On the F-4J, a similar problem exists. We observed a group of three men attempting to remove the steel pin; it takes considerable effort and patience. Unfortunately, the steel pins do not wear, rather the aluminum hinge does. They become elongated. They are not a stock item so the hinge must be repaired. Cracked segments are cut off. The worn holes are rebushed with 303 stainless steel. The original hinges on the F-4 are 7075 Al-T13. The manual calls for their lubrication every seven days. The following designations apply to problem areas.

| | | |
|---|---|---|
| Inner wing flap hinges | P/N 32-11040-30,-40 | (01-245-FDA-3-1.2) |
| Outer wing flap hinges | P/N 32-15549 | (01-245-FDA-3-1.4) |

Actually these are ideal applications for solid film lubricants which if properly applied should last the lifetime of the plane, from a theoretical point of view. They would certainly facilitate the removal of the pins upon rework. They are also sufficiently enclosed so that dirt would not be a major problem. The use of solid films in such applications should be given primary consideration. As pointed out by one of the engineers, this would be an ideal application for an oil resistant solid film lubricant. The solid film would then act as a back-up when maintenance is neglected. For this purpose a phosphate film may suffice.

## 3. Wing Folds and Latches

There were very few problems reported with the wing folds except occasional rebushing. This was particularly noted on the F-4. On the A7 UHT wing fold bearing, a 90% loss is reported. No particular reason can be found for this situation. The applicable manual (01-45AAA-4-1) describes the configuration. The bushings (PN 215-70452-1 to -6) are straight journals. The pin is hollow (PN 215-70112-2) with a grease fitting at the end. A hole in the pin allows grease to reach each bearing. Actually steel

bushings would not be recommended, however this should not cause the problem; it is more likely associated with the distribution of grease in the bearing. Generally, the grease is packed around the bearing so the oil can drain to the surface. Here the grease is contained in the pin with only a small hole for oil drainage. A better arrangement would be to put a grease groove in the bearing so that the grease would be stored there.

A problem found was in the S-2B and the C1A wing lock fittings. On both of these aircraft a male and a female part mesh at the wing fold. These parts act as the locating surface for the two wing portions. A pin is then inserted in a hole in the wing lock fittings to lock the wing in place. No lubricant is presently used on the surface of the fittings and damage results in service. On the C1A, the parts are made of 7075 Al and on the S2D and E, the parts are 4130 steel. There are approximately 30 male and female fittings per aircraft (e.g. P/N 121 WM1-0063-5). We were told that about 25 to 35% of these fittings were damaged. These were buffed and ground in rework. Depending upon the amount of damage it takes up to one hour per fitting to rework; thus about 15 to 20 hours per aircraft. This is a natural application for a solid film lubricant accordingly a lubricant conforming to military specification MIL-L-8937 is recommended and in service an aerosol spray of MIL-L-23398.

## 4. Rod End Bearings

Solid films have found increasing use in rod end bearings. Accordingly, a discussion was held at each NARF on the condition and rework of rod end bearings. In most of the wing shops, they did not feel they were any problem. On the S-2 it was reported that many were seized but they could be salvaged. One bearing shop reported that they discarded most of them rather than try to salvage them. It is generally concluded that adequate service is obtained from the bearing considering the cost and there was little concern over their performance.

## 5. Bellcrank Bushings

No shop reported any serious problems except one on the F-8J. This problem has now been solved.

### 6. Actuators

Hydraulic actuators are discussed elsewhere. One problem was encountered in the P3A wing flap actuator (SPL 5568-3). This ball jack screw contains several severe wear areas. The thrust rolling contact bearing is having 80% replacement because of fretting of the balls in the races. The manual calls for the parts to be phosphated (MIL-P-16232) and lubricated with MIL-G-23827. Based upon the superior anti-fretting properties exhibited by MIL-G-81322 greases in several different aircraft applications, it is recommended that it be substituted for MIL-G-23827 in this application.

## F. Fastener Corrosion

Alameda NARF has reported a problem concerning the corrosion of fasteners lubricated with solid films. This problem was investigaed in some detail.

The problem first arose in 1963 on the A-3 where corrosion was noted in the high stress wing spar cap flanges (structural base of the wing). It was stated that there was cracks with the fasteners which had the dry film lubricant and no cracks with the nonlubricated fasteners. A photograph of the phenomena shows what appears to be intergranular corrosion of the exfoliation variety which can seriously weaken the structure. The rivet in this application is a high shear type which consists of a steel shank on which an aluminum collar is swaged. Both parts are coated with a solid film lubricant (composition indefinite). Apparently this is the only aircraft where the problem has been noted (some disagreement here) and as a result an LES has been issued (GEN/AL 15-0-0050) to remove solid lubricants from all fasteners and fastener systems such as Huck bolts, collars, nuts, Hi-Lok fasteners, blind fasteners, Hi-Shear fasteners, and anchor nuts and to apply a coating of lauric acid or cetyl alcohol. This practice is being rigidly adhered to.

Douglas Aircraft in a report, we were told, concluded that it was not due to the solid lubricant film but rather it was stress corrosion cracking due to the fact that the NARFS put too high a load on the fasteners.

Metallurgical examinations conducted at the Alameda Materials Laboratory

(Report NARF-341-CFC/Bs-167-16) concluded that the wing spar had been improperly heat treated, leading to larger than normal size copper rich hardening constituents percipitating along the grain boundaries, and this was the principal cause of the low resistance of the spar cup to stress corrosion.

Because of these results a specific point was made to question each of the other NARFS concerning their experience with fastener corrosion. The general conclusion was that there was always some corrosion problems with fasteners (with or without solid film lubricants) but not so severe as that reported by Alameda.

A discussion of this problem was also held with several manufacturers of fasteners and also with the solid lubricant vendors. It was found that in 1958 when the A-3 was manufactured the fasteners were supplied with the following solid lubricants.

| | | |
|---|---|---|
| DAG 206 | ----- | $MoS_2$ in water insoluable Polyglycol |
| DriLube 831 | ----- | Low molecular tellemer of Teflon and fluoronated hydrocarbons |
| Everlube 620 | ----- | $MoS_2$ with a modified phenolic binder |
| Electrofilm 4396 | ----- | $MoS_2$, graphite, phenolic binder. |

A second possible source of corrosion has been attributed to the use of a particular fine grade of $MoS_2$ in films on fasteners. This grade contained excess molybdenum oxide which could induce corrosion. This grade is however, no longer available.

It was also found that many of the fastener manufacturers have now eliminated the graphite from the solid films but some still use graphite containing films. The use of solid films is not considered essential by the manufacturers and are only applied if the customer requires it.

Thus, it can be seen that fasteners were, and are now available with graphite containing films which have been condemned as corrosion prone. For this reason Alameda does not feel that any corrosion resistant solid lubricant film can be

used; they are unable to distinguish between the two.

Accordingly, two possible sources of fastener corrosion were available and could have been aggravated by other circumstances existing on the A-3. Unfortunately, the conditions still exist and the question still remains as to the most appropriate solution. The elimination of the solid film is one solution, but raises the question as to the need for solid lubricants originally. It has been suggested, but not verified by the literature, that the solid lubricants are on fasteners for two reasons; first, to prevent fretting corrosion and secondly, to aid in their disassembly. A literature survey and possibly experimental data are needed to conclusively answer this question. If they are not absolutely necessary, the simplest procedure would be to eliminate them; however, if they are needed steps should be taken and arrangements made with the manufacturers to apply corrosion resistant films which can be identified in service. An equally acceptable and probably more practical solution would be to buy the fasteners uncoated and apply a corrosion resistant film at the NARF.

Alameda's experience with these fasteners has raised many questions concerning the corrosion of metals by solid lubricants. Because of this, some sort of instruction is necessary to clarify and update the NARF engineers on this important subject. Although this is beyond the scope of the present study the following information was accumulated during the course of the survey.

The Army at its Rock Island Arsenal facility has published (20) information which they feel conclusively shows that graphite is the cause of corrosion. Accordingly, they have developed films without graphite which contain a corrosion inhibitor. These films are now covered by a military specification and they are being used by the Army as corrosion resistant films on cannon ar' other military hardware.

.he Air Force, at its Warner Robins facility, cited evidence which it contends demonstrates the corrosion induced by graphite in MIL-L-8937 films. They feel that graphite should be excluded from formulations of solid film lubricants unless it can be demonstrated that it is needed in specific applications. Their

chemical laboratory is completing an investigation of the corrosion behavior of solid film lubricants.

NADC has investigated the corrosion resistance of solid film lubricants. They find that the best lubricants from a corrosion standpoint do not contain graphite but not all graphite containing compounds can be considered to give poor corrosion resistance.

The corrosion manual (NAVAIR 01-1A-509) clearly discourages the use of graphite in lubricants but has little to say about the use of $MoS_2$.

At the NARFS the engineers and shop foremen were questioned concerning their experience with corrosion by solid lubricants in any form. The consensus was that there were problems when graphite was used but no examples could be cited for corrosion by $MoS_2$ or other solid lubricants.

For our own purposes the authors carefully inspected the wing fold area of the A6 where there are 22 lubrication points requiring $MoS_2$ greases and the main landing gear where there are 52 such points. Although only a few aircraft and landing gears were available, discussions were also held with the shop foremen to ascertain the extent of corrosion in these two areas. No corrosion was evident in the wing fold area. In the landing gear. two areas were noted where corrosion was frequent:

- In the nose landing gear outer cylinder (P/N 9936 FOO) corrosion is frequently evident between a bronze bushing and its aluminum housing. This problem has been solved, according to the shop formen, by applying a sealant to the interface.
- In the landing gear spring and arm (P/N 9937A-7B Manual 01-85-ADA-73B) there are several steel bushings used in aluminum housings. In service they become frozen due to corrosion. Although there is lots of $MoS_2$ grease around the corrosion is only in the bearing contact area and not in surrounding areas. Thus it may be due more to the galvanic couple than to the $MoS_2$.

Therefore, from 74 lubrication points in corrosion sensitive areas only two corrosion problems could be cited, which might be attributable to other causes. This, of course, is only one example but it does indicate the lack of a general problem.

In all the visits with the materials engineers and the shop foremen the question was asked if they had seen corrosion which they could associate with solid film lubricants. In almost all cases the answer was negative, however a few cases can be cited:

- J79 15th stage compressor blade which is lubricated with DAG 213 (graphite) is noted to have corrosion and pitting.
- F8J outer panel droop well cranks and walking beam assembly (P/N 26-760508-2) 4000 series steel uniballs and bronze bushing coated with solid lubricant. Original lubricant unknown.
- A-7 brake bolt - Uses MIL-T-5544 graphite in petrolatum is severely corroded and sometimes sheared in disassembly.
- A-3 deceleration parachute release yoke assembly P/N 3554459-Solid film is specified on drawings with no name or mil specification. In service the film is worn off. Wear and corrosion are evident. Actual lubricant is not known.
- P-3 storage latter guide (P/N 919667-1) - Film is worn off the hinge with considerable wear and damage to the part. There is evidence of corrosion under the dry film.

With these applications it was difficult to determine what lubricant is on a part since no knowledge was on hand as to the previous rework, if any, or if the film had been applied in manufacture. The cause of the corrosion is not significant since in many of these applications steps have been taken to solve the problem. The significant point is that these were the only examples of corrosion reported by the NARFS.

An item of major importance is the fact that graphite greases or thread compounds MIL-T-5544B is still used and is in fact called for in many manuals

particularly those concerned with brake rework.

The Air Force has cited corrosion problems on wheels and wheel bolts which they attribute to the use of this graphite thread compound.

Another item of particular significance was pointed out by the No h Island engineering personnel. That is that the present corrosion test was conducted under static conditions with new films, while in service the films had experienced considerable sliding action. They felt that a dynamic corrosion test would be much more meaningful and may indicate some results which differ from current thinking. It is hard to disagree with this suggestion. Further investigation of this point yielded little information from the literature. However, Murphy ran several coatings in a combination friction corrosion test and concluded that the wearing away of the solid lubricant coating decreases the effectiveness of the coating as a corrosion exhibiting barrier (24).

Almost all of this evidence suggests that once graphite is eliminated there is no corrosion problem. However, what is needed is conclusive laboratory data obtained under dynamic conditions, with a variety of metals and lubricants. This question should be answered before a great deal of time and effort is wasted in discussion and consideration of the problem.

Whatever the case, the dynamic test is recommended for qualification of solid film lubricants.

## VII. RESEARCH AND DEVELOPMENT SUMMARY

Solid film lubricant R & D has primarily concentrated on developing bonded films with greater and greater wear life. The present survey, by examining the ways solid lubricants are actually used in naval aircraft, the realities of aircraft operating condtions, and the practical considerations of maintenance and rework, has brought about the realization to all the specialists involved, that a need exists to re-define the direction of solid lubricant R & D.

In order of importance, the first need is to develop solid lubricants which will function in the presence of oils in greases. Present solid film lubricants lose much of their effective wear life if rubbed in the presence of fluids. Most of these materials presently pass a fluid compatibility test which immerses them in the given fluid for some period of time and then tests then after being dried off. A true test would rub the films while wet; that is the only meaningful way to determine fluid compatibility. In actual aircraft use, no matter how carefully controlled the film application processing, the films can become fluid contaminated, for two reasons. Firstly, many points exist which have to be oil or grease lubricated and it is a practical impossibility to prevent these materials from being applied to the solid films as well. Secondly, leakage from hydraulic components is a normal occurrence, and the leakage easily contaminates the solid films. Therefore, the greatest present need in the solid lubrication of aircraft is the development of solid films which retain their effectiveness when fluid contaminated.

The second greatest need is the development of a true general purpose film. The NARFS have more than 100 different, proprietary, solid film lubricants available to them all with limited shelf life, together with differences in processing, cleaning, and curing. With far too many products available to choose from, and specified in manuals, a natural reduction in the number of films used has been occurring, with the result that films non-multi-purpose in abilities, have been improperly used in applications where they could only fail. This is really an R & D problem for it is both unrealistic and impractical to expect a facility to apply a great many different solid film lubricants. A true multi-purpose material, having the following properites would solve this

problem:

- Aerosol applicable
- High wear life capability
- High and low temperature capabilities
- Corrosion resistant
- Extended shelf-life

If not all of these characteristics can be developed in a single material, then the high temperature capability could be sacrificed. The addition to this list of requirements, of being able to function in the presence of fluids, would be highly desirable, but possibly not presently obtainable.

The third greatest need is the development of a solid film lubricant whose effectiveness is less critically dependent on tight processing controls. Present solid film lubricants exhibit optimum wear life only when applied over a very narrow range of film thickness (say, 0.0002 - 0.0005). Obtaining this film thickness range demands great skill and experience by the spray operator, and conflicts with the normal practice and requirements of NARF spray operations. In order to eliminate critical requirements for operator skill as well as a dependency on a narrow range of film thickness, development should be undertaken to provide films with excellent wear properties based on a large allowable film thickness range. Present solid film lubricants require a many stepped sequence of surface cleaning and pretreatment, in order to obtain long wear life. This many stepped sequence of events is very inconvenient to production requirements, is prone to error, and together with curing time, represents 80 (eighty) percent of the film processing time. Recent developments in the field of organic coatings have shown that outstanding adhesion combined with abrasion resistance can be achieved by essentially single step processing. On this basis, it is considered that solid films can be readily perfected with simple processing procedures, and such development should be undertaken.

The previous recommendations are highly recommended for implementation based upon the realities of solid lubricant use in practical situations. The remaining recommendations would improve the usefulness of solid lubricants for air-

craft applications.

Corrosion protection of metal surfaces by solid lubricants is a vital requirement. Current test procedures are based on essentially unworn solid films under static test conditions. However, in service, film disruption occurs instantly during start-up operations and continues during the service life of the part There is a critical need for research techniques, which provide information on the corrosion protection of disrupted films. Further, little if any technology has been aimed at understanding the mechanism of corrosion protection by chemical addition agents for solid film lubricants. Based on this severe limitation, a study to understand the mechanism for corrosion inhibition in solid film lubricants especially under service conditions is recommended.

Technology can be developed which will allow worn solid films to be touched up by the application of a new film on top of the old film. In service, solid film lubricated surfaces experience film wear and burnishing. During rework, the wear will necessitate the re-solid lubrication of the surface, but the burnishing makes it difficult and bothersome to remove all of the old film. It is not presently known whether removal of the old film is really necessary, and if not, considerable savings in manhours could be realized. An R & D program should look into the development of practical ways to apply new solid films on top of old films, including possibly first chemically cleaning the surface or mechanically roughening it. The associated question of how to properly remove an old worn film should also be examined.

Improved high temperature films are still needed. Critical rubbing components exist, such as the dove tails of jet-engine turbine blades. The rubbing of unlubricated components results in an excessive wear rate which causes reduced part life. Much work has gone into the development of high temperature solid film lubricants, and based on this work it should not be too difficult to develop compositions and military specifications suitable for naval aircraft usage; it is recommended that this be done.

Another desirable feature would be to develop simplified procedures for applying films which are intended to be used only for anti-seizure applications.

Many present aircraft solid lubricant applications are screw threads or latches, which only undergo a few cycles during their lives. The present use of films developed for extended wear life, where such life is not required, leads to expensive and unnecessarily complicated processing. It should not be too difficult to develop compositions and military specifications for anti-seizure solid film lubricants, which do not have extended wear life requirements and need only simple processing, it is recommended that this be done.

In summary then, three critical and four highly useful solid lubricant R & D needs exist:

Critical R & D Needs

1. Development of solid films functional in the presence of fluids
2. Development of a true general purpose film
3. Development of films whose effectiveness is not critically dependent on tight processing controls

Additional Highly Useful R & D Needs

1. Study to understand the basis of corrosion inhibition in solid film lubricants
2. Development of technology for putting new films on top of old films
3. Development of film compositions and military specifications for high temperature use
4. Development of simplified processing procedures for film used in anti-seizure applications

## VIII. NEW NAVY BUYS

Those problems observed in this study which are general, that is, are found in many different designs have a strong likelihood of recurrence in future Navy buys unless steps are taken to prevent this. Of course, improved communication to vendors about current problems would be helpful in this regard, but this alone is not sufficient, for vendors are likely to feel, rightly or wrongly, that the Navy wants things done in the conventional manner, whether or not this manner truly meets the requirements of operation. The taking of positive steps by the Navy should dispel any such notion.

### Proprietary Lubricants

Many engineering rework hours are wasted in procurring or changing proprietary compounds listed in the manuals. These should be eliminated in the preparation of new manuals.

### Landing Gear Brakes

The spline friction problem, previously described is bound to re-occur, unless it is required that multiple disk brakes have their disk key surfaces solid film lubricated with extreme environment bonded solid film lubricant, applied in such a manner as to last for the designed wear life of the disk face.

### Landing Gear Brake Hydraulic Actuation

The aluminum and magnesium hydraulic piston and cylinder wear problem, previously described, is inherently associated with that choice of rubbing materials. Manufacturers should be required to use wear resistant materials on these surfaces, the choice being up to them, which will meet certain specified wear rates in this application. The wear life of this system should be a purchase specification.

### Hydraulic Pistons and Cylinders

General hydraulic pistons and cylinders presently having surfaces composed

of steel, aluminum, and chrome plate, do not have sufficient wear and surface damage resistance. Hydraulics piston and cylinder manufacturers should be required to meet wear and surface damage resistance design and test specifications. This will necessitate their substitution of better surface materials.

## Wear Life

Critical components whose operating interval is limited by wear should be required to meet specific wear life specifications. The present lack of such specifications, results in short operating interval and high rework components being built into systems.

## IX. CONCLUSIONS AND RECOMMENDATIONS

A survey of the application of solid lubricants in the Naval Aircraft Rework Facilities has been conducted. Thirty-four recommendations based upon this survey are listed in Appendix I. These have been submitted in a modified form to the Naval Air Systems Command for review. The general conclusions from this study are as follows:

1. Concerning solid lubricants in oils and greases no major problems were uncovered except that graphite greases are recommended in brake overhaul manuals in spite of evidence that they may contribute to corrosion.

2. Very few solid lubricant composite materials are used in naval aircraft in spite of their advantages over the steel bearing-grease system. It is possible that if specifications on such materials were issued their use would be encouraged.

3. Many improvements could be made in the bonded solid films which are presently used and the manner in which they are processed.

4. Solid films are generally performing satisfactorily in service as far as their wear life is concerned. Problems can usually be attributed to either poor application techniques or corrosion.

5. Many applications were found where solid film lubricants could replace the current lubrication practice with a considerable saving in rework hours and parts.

6. Many wear problems were encountered where solid lubricants are not applicable (hydraulic cylinders, bushings, and seals). There is a need for increased utilization of wear technology and a particular need for improved wear resistant materials.

7. Seal leakage is a major problem which should be investigated in detail by the Analytical Rework Program.

8. Lack of "feedback" to aircraft designers results in continual problems. It is believed that this is the result of the acceptance of excessive wear as the "norm" when in reality few parts if properly designed and lubricated should wear.

9. Research and Development which at present is mostly concerned with extended wear life should be redirected toward the following objectives which are more consistent with their utilization:

   a. Oil resistant films
   b. Multi-purpose films
   c. Films which are less sensitive to thickness and pretreatments

Based on these conclusions the major recommendations of Table 16 have been formulated. The numbers refer to the specific recommendations of Appendix I.

TABLE 16

ANALYTICAL REWORK PROGRAM
APPLICATION OF NEW AND IMPROVED SOLID LUBRICATION TO NAVAL AIRCRAFT
CONTRACT NO. N62269-71-C-0177 AIRTASK WR-1-0560

MAJOR RECOMMENDATIONS

LUBRICANTS

Remove Proprietary Lubricants from Rework and Manuals (8)*
Prepare Improved Product Mix (11)
Prepare Manual on Solid Film Lubricants and Processing (11)
Direct Research Toward Multi-Purpose Lubricants (14)
Write Specifications for Oil Resistant and High Temperature Films (14)
Lubricant Purchasing Practices (9,15)

PROCESSING

Use Single Facility and Operator for Solid Film Application (11)
Institute a Training Program in Solid Film Processing (10)
Establish Simple Quality Control - Tape Adhesion and Film Thickness (20)
Eliminate Unneeded Processing (11,22)
Improved Shot Peening of Compressor Blade Roots (18)

LANDING GEAR

Apply High Temperature Solid Lubricant Films to Brake Disk Spline Areas (1,2,3,24,25)
Find Treatments to Prevent Wear and to Salvage Brake Cylinders (13,26)

HYDRAULICS AND PNEUMATICS

Apply Alameda Treatment for Rework of Chrome Surfaces (17)
Find Treatments to Prevent Wear and to Salvage Hydraulic Pistons and Cylinders (30)
Salvage Servo Control Valves by Coating with Solid Lubricants (28)
Apply New Seal Technology (21)

WING SYSTEMS

Apply Solid Film Lubricants to Wing Lock Fittings (12)
Apply Corrosion Resistant Solid Lubricant to Hinge Bearings (31)
Apply Corrosion Resistant Solid Lubricant to Control Surface Tracks (32)

AIR FRAME

Establish the Need for Solid Film Lubricants on Fasteners (19)
Substitute Self-Lubricating Composites for Steel and Stainless Bushings (4)

APPLICATION OF WEAR TECHNOLOGY TO NAVAL AIRCRAFT

Designate a Wear Prevention Control Team (29)
Use Existing Facilities and Equipment to Apply Advanced Wear Resistant Treatments (17,23,27)
An Application Review Should be Conducted on the Utilization of Advanced Wear Technology (23)

---

* The numbers in the parenthesis correspond to the formal recommendation number in Appendix I, which follows.

## X. REFERENCES

1. Johnson, R.L., "A Review of the Early Use of Molybdenum Disulfide as a Lubricant," Presentation NLIG Annual Meeting, New Orleans, Louisiana 1967.

2. Bell, M.E., and Findlay, J.H., "Molybdenite as a New Lubricant," Physical Review, 59, p.922 (1941).

3. Boyd, John and Robertson, B.P., "The Friction Properties of Various Lubricants at High Pressures," Trans. ASME 66, No. 1, p. 51, (1945).

4. Godfrey, D. and Nelson, A.C., "Oxidation Characteristics of Molybdenum Disulfide and Effect of Such Oxidation on its Role as a Solid Film Lubricant," NACA TN 1882 (1949).

5. Davis, R. (Ed.), "Friction, Durability, and Wettability Properties of Monomolecular Films on Solids," FRICTION AND WEAR, Elsevier, 1959.

6. Horwedel, L.C., "Solid Lubricants as Organic Finishes," 47th Annual Proceedings American Electroplaters Society.

7. Devine, M.J., Lamson, E.R. and Bowen, J.H., "Inorganic Solid Film Lubricants," Journal of Chemical and Engineering Data, Vol. 6, No. 1, (1961).

8. Peterson, M.B., and Johnson, R.L., "Solid Lubricants for Titanium," Lubrication Engineering, Vol. 2, No. 5, p. 297 (1955).

9. Lipp, L.C. and Fickenwirth, F.I., "Solid Lubricant Applications on the United States Supersonic Transport Airplane," Proceedings of the AFML-MRI Conference on Solid Lubricants, Air Force Materials Laboratory, Wright-Patterson AFB, Ohio, AFML TR70-127, 1970.

10. Deemer, E.J., Private Communication

11. Van Wyk, J.W., "$MoS_2$ Solid Lubricant Composites," Proceedings of FFML-MRI Conference on Solid Lubricants, AFML TR70-127, Air Force Materials Laboratories, Wright-Patterson AFB, Ohio, 1970.

12. Stupp, B., "$MoS_2$ and Related Solid Lubricants," Lubrication Engineering, Vol. 14, No. 4, p. 159 (1958).

13. Hopkins, V., and Campbell, M., "Friction and Wear Life of Selected Solid Lubricant Films at -100F, 80F, and 400F," Lubrication Engineering, Vol. 25, No. 11, p. 43 (1969),

14. Lipp, L.C., "Lubrication of the Supersonic Aircraft," Lubrication Engineering 24, 4, p. 184 (1968).

15. Lamson, E.R. and Devine, M.J., Patent No. 3,079,204, February 26, 1963.

16. Hopkins, Vern, "MLF-5 An Inorganic Solid Lubricant Film," Proceedings of USAF - SwRI Aerospace Bearing Conference, San Antonio, Texas, 1964.

17. Williams, F.J., "The Development and Testing of a New Ceramic Bonded Dry Film Lubricant," Proceedings of USAF-SWRI Aerospace Bearing Conference, San Antonio, Texas, 1964.

18. Johnson, R.L. and Sliney, H.E., "High Temperature Friction and Wear Properties of Bonded Solid Lubricant Films Containing Lead Mono oxide," Lubrication Eng., Vol. 15, No. 12, p. 487, (1959).

19. Sliney, H.E., Strom, T.H., and Allen, G.P., "Fluoride Solid Lubricants for Extreme Temperatures and Corrosive Environment," ASLE Trans., Vol. 8, No. 4, p. 307, (1965)

20. Meade, F.S. and Murphy, G.P., "A Corrosion Protective Resin-Bonded Dry Film Lubricant System Which Provides Good Wear Life," Rock Island Arsenal Report 61-4164 (1961).

21. Devine, M.J., Lamson, E.R. and Bowen Jr., J.H., "The Effect of the Chemical Composition of Metals in Solid Lubrication," Paper presented at Meeting American Chemical Society (1963).

22. Berry, L., "Solid Lubricant Coatings," Paper No. 58AV20, Presented to ASME-ARS Joint Aviation Conference, Dallas, Texas, 1958.

23. Barry, H.F. and Binkleman, J.P., "$MoS_2$ Lubrication of Metals," Lubrication Engineering, Vol. 22, No. 4, p. 139 (1966).

24. Murphy Jr., George, "Summary of Solid Lubricant Research by Rock Island Arsenal Research Laboratories," Rock Island Aresenal Report 67-3062, (1967).

25. Azzam, H.T., "Evaluation Methods and Techniques of Solid Lubricants in Oils and Greases," Notes on Solid Lubricants, Rensselaer Polytechnic Institute, 1966.

26. Lancaster, J.K., "Solid Lubrication," Unpublished Report AEI Industries.

27. Devine, M.J., Lamson, E.R., Cerini, J.P., Carroll, R.J., "Solid Lubricants," Paper No. 20, Conference on Lubrication and Wear, London, 1967. Inst. of Mechanical Engineers.

28. Barwell, F.T., and Milne, A.A., "The Use of Molybdenum Disulphide in Association with Phosphated Surfaces," Sci. Lubrication, Vol. 3, No. 9 p. 10 (1951).

29. DiSapio, A. and Lindsey, F., "Some Effects of Oscillating Motion on Bonded Solid Film Lubricants," Paper Presented at ASLE Meeting, Chicago, Ill., May 1970.

30. Jones, John, "Low Load Oscillating Tests of Bonded Solid Lubricants and Composites," Lubrication Engineering, Vol. 24, No. 10, p. 464 (1968).

31. Lipp, L.C., "Lubrication of the Supersonic Aircraft," Lubrication Engineering Vol. 24, No. 4, p. 184 (1968).

32. Spalvins, T., "Deposition of $MoS_2$ Films by Physical Sputtering and Their Lubrication Properties in VAC," ASLE Trans. Vol. 12, No. 1 (1969).

33. Hopkins, V., Hubbell, R. and Kremith, R., "Plasma Spraying, A New Method of Applying Solid Lubricants," Lubrication Engineering Vol. 24, No. 2, p. 72, (1968).

34. Spalvins, T., "Energetics in Vacuum Deposition Methods for Depositing Solid Film Lubricants," Lubrication Engineering, V. 25, No. 11, pp. 436-441, (1969).

35. DiSapio, A. and Maloney, James, "The Lubricating Performance of an "in situ" Process $MoS_2$ Film in Air and in Liquids," ASLE Transactions, Vol. 11, p. 56, (1968).

36. McConnell, B.D., Weiser, L.E. and Mecklenburg, K.L., "Wear Life Improvement of a Solid Film Lubricant," Lub. Eng., Vol. 24, No. 2, p. 81, 1968.

37. Peterson, M.B., and Murray, S.F., "Requirements of Materials for Sliding and Rolling Contacts," Chapter 9, BOUNDARY LUBRICATION - AN APPRAISAL OF WORLD LITERATURE, ASME, 1969.

38. "The Frictional Properties of Molybdenum Disulphide," J. Inst. Petrol. 42, p. 316 (1956).

39. Hopkins, V. and Gaddis, D., "Effect of Surface Finish and Hardness on the Wear Life of an Inorganic Solid Lubricant Film," Lubrication Engineering, Vol. 25, No. 1, (1969).

40. Solomon, G., DeGee, A.W.J., Zaat, J.H., "Mechano-Chemical Factors in $MoS_2$-Film Lubrication," Wear, Vol. 7, No. 1, p. 87, (1964).

41. DU Non-Lubricated Bearings: Engineering Data and Selection, Schutte and Koerting Co., Bulletin 33, 1964.

# APPENDIX I

# FORMAL RECOMMENDATIONS

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 1
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: A-7 Landing Gear Brake: Excessive Disk and Key Usage

BACKGROUND

Bonded solid lubricant films are not used on critical dry sliding surfaces with the following consequences:

1. Rotating disks (PN 9542898; FSN 1RM-1630 - 991-4325-GA) are short-lived due to excessive spline wear and spline friction moment induced lining cracking. As a result, Alameda alone, in the past 6 months used 274, while total Navy usage was 1160 at $73. Potential yearly savings to the Navy is $160,000.

2. Stationary disks (PN 9534357; FSN 1RM-1630-991-4319-GA) would last longer if splines were lubricated. Alameda alone used 65 in the past 6 months while total Navy usage was 2442 at $63.

3. Key disk drives (PN 9536635; FSN 1RM-1630-809-2641-GA), which are the mating part to the rotating disks, have excessive wear. As a result Alameda alone in six months used 110; Navy wide usage has been 1176 in the past 12 months, at $2.90. Potential yearly savings to the Navy is $6,800.

RECOMMENDATION

On A-7 Landing Gear Brake the sliding surfaces of the following parts should be lubricated with extreme environment solid film lubricant MIL-L-81329A.

a) Rotating disk (PN 9542898; FSN 1RM-1630-991-4325-GA)
b) Stationary disk (PN 9534357; FSN 1RM-1630-991-4319-GA)
c) Key disk drive (PN 9536635; FSN 1RM-1630-809-2641-GA)

The following surface pretreatments should be used in the parts processing:

a) Vapor degrease with trichlorethylene
b) Vapor blast-120 mesh alumina
c) Phosphate as specified by Type M class 3 of MIL-P-16232

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 2
Contract No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: A4E Landing Gear Brake: Excessive Disc Usage

BACKGROUND

Bonded solid lubricant films are not used on critical spline areas of the Brake Disc (PN 9531709; FSN 1R-1630-524-2600-DA) leading to excessive spline wear and consequent parts replacement. As a result Alameda alone, in six months, used 314, while total Navy usage was 1791, at $40.82. Potential yearly savings to the Navy is $102,500.

RECOMMENDATION

On A4E Landing Gear Brake Disk (PN 9531709; FSN 1R-1630-524-2600-DA), the spline surfaces are to be coated with extreme environment solid film lubricant, MIL-L-81329A. The following surface pretreatments should be used in the parts processing:

a) Vapor degrease with Trichlorethylene
b) Vapor blast with 120 mesh alumina
c) Phosphate as specified by Type M class 3 of MIL-P-16232

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 3
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: P3B Landing Gear Brake: Excessive Brake Disk Dishing and Rotating Disk Replacement

BACKGROUND

Bonded solid film lubricants are not used on critical dry sliding surfaces with the following consequences:

1. The steel brake disk (PN 133-255; FSN 1RM-1630-998-7937-BP) undergoes rework because of dishing. The rework involves pounding the disk flat with a hydraulic hammer. This dishing is caused by a combination of thermal stress and the spline friction twisting moment. This moment can be relieved by solid filming the spline area of the disc.
2. The rotating disk (PN 244-212; FSN 1R-1630-998-7936) has spline wear and face chipping. Alameda alone in a six month period used 102, while total Navy usage was 414.

RECOMMENDATION

On the P3B Landing Gear Brake the spline sliding surfaces of the following parts should be lubricated with extreme environment solid film lubricant MIL-L-81329A.

a) Brake Disc (PN 133-255; FSN 1RM-1630-998-3937-BP)
b) Rotating Disc (PN 244-212; FSN 1R-1630-998-7936)

The following surface pretreatments are recommended in the parts processing:

a) Vapor degrease with Trichlorethylene
b) Vapor blast with 120 mesh alumina
c) Phosphate as specified by Type M class 3 of MIL-P-16232

Date: April 29, 1971
Recommendation No. 4
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Replacement of Steel Bushings in S2D Main Landing Gear

BACKGROUND

Steel bushings are found throughout many types of reworked Naval Aircraft. For example, the S2D main landing gear bushings (PN QP30990-2; QP31056-1,2,3). They may or may not have a grease fitting which may or may not be used. Most steel bushings are damaged in service, requiring about 60% replacement. Usually, these must be made in-house since they cannot be purchased. In most instances the bearing is only lubricated upon reassembly. The cost of disassembly and assembly is quite high. For the two types of bushings mentioned above, Quonset Point in the last six months, has had to manufacture 40 of the first type and 20 of the second type.

The basic question this raises is why bare steel bushings? Clearly many composite materials exist, not to mention bronzes, which are obtainable either as bearings or can be made into bearings, or can be used as coating on bushings; and which would need virtually no re-work once put into service in lieu of bare steel bushings. In fact, this is already being done in non-Naval applications. Union Carbide Coating Service applies aluminum bronze by plasma spray to the tail stabilizer hydraulic cylinders and landing gear bushings of the Boeing 707 and 727. Other materials used on other aircraft rework wear areas include plasma sprayed chrome oxide (for the C-141) and tungsten carbide.

RECOMMENDATIONS

NARF engineers should substitute self-lubricating composite materials or wear resistant materials coated bushings for the present steel S2D main landing gear bushings, during rework. In order to do this, they will have to consider each bushing's operating conditions and requirements (i.e., load, motion, speed, number of cycles, permissible clearance change, etc.). Some suitable materials which should be considered for this purpose include the Molalloy sintered composite bushing materials available from Pure Carbon Company, and plasma sprayed aluminum bronze, chrome oxide, and tungsten carbide available from Union Carbide Coating Service.

Date: April 29, 1971
Recommendation No. 5
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Solid Lubricant for A-4 and A-7 Inertia Reels

BACKGROUND

These reels hold the belts which restrain the pilot against high G forces. They are presently being relubricated with an aerosol spray 26A. This film is flaking off in service and locking up the reels. The locking of the reels causes a personal hazzard to the pilot. Since Aerosol sprays have a tendency to do this and are known to give shorter wear life, a regular bonded coating is preferred. In some applications like this one, solid lubricants are not used because even the small wear particles can jam a delicate mechanism. Secondly, the solid lubricant may be disliked if it contaminates the belts or clothing of the pilot. In such a case a very light oil should be used.

RECOMMENDATION

It is recommended that a regular bonded film conforming to MIL-L-8937 with appropriate pretreatments be used or a very light oil.

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 6
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: S2A, C1A Landing Gear Brake: Excessive Usage of Wear Adjuster Pin Assembly

## BACKGROUND

A group of brass wear adjuster pin assemblies (PN 147633; FSN RM-1630-041-4909-xx6x) are used to take up the wear as the disc brake pack wears. These parts are presently being solid lubricated with an aerosol can, but this has proven inadequate as shown by Quonset Point's usage, due to wear alone, in the last y months of 622. The use of a high temperature bonded solid lubricant should completely alleviate the problem.

## RECOMMENDATION

The S2A, C1A landing gear brake wear adjuster pin assembly (PN 147633; FSN RM-1630-041-4909-xx6x), before placement into the brake should be coated with extreme environment solid lubricant film MIL-L-81329A. The following surface pretreatments are recommended in parts processing:

a) Vapor degrease with Trichloroethylene
b) Vapor blast with 120 mesh alumina
c) Chromate as specified by MIL-C-5541

Date: April 29, 1971
Recommendation No. 7
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Glass Bead Blasting

BACKGROUND

At Pensacola and Alameda NARF's glass beads are used for surface roughening before the application of the solid film lubricant. Work by Devine (for example, see Chapter 12 - Solid Lubricants, M.J. Devine from "Environmental Effects in Polymeric Mateiials," Interscience, 1968) has shown busting with glass spheres as a pretreatment gave a wear life of 3 minutes for a standard solid lubricant film compared with a wear life of 217 min. for 60 mesh Silicon Carbide and 134 minutes for 60 mesh $Al_2O_3$. Maximum wear life of 315 minutes was obtained with 120 mesh iron shot. Presumably the glass is pulverized, and retained on the surface. This lowers the wear life of the film.

RECOMMENDATION

Glass beads should not be used prior to applying a solid film lubricant. The more conventional grits such as $Al_2O_3$, silicon carbide or sand are preferred.

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 8
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Use of Proprietary Solid Film Lubricants

BACKGROUND

This survey has shown that many proprietary compounds are used in Naval rework which are not on the qualified product list. This situation has come about because of the specification of such compounds in the aircraft manuals. For example, NAVAIR 02B-100AA-6-2, Par. 6-396 specifies "Apply Fel-Pro C-200 per SPOP 146 or Ease-Off 990 per SPOP 145" on compressor blades. In addition, two NARF's use Electrofilm 4396 almost exclusively. This film has been shown to be corrosion prone. There are qualified films with improved properties which should be substituted for these compounds. Since there are many bonded lubricant films (i.e., 130 commercially available materials) and a variety of categories of use, information on the equivalence of solid lubricant films is very much need by NARF materials engineering. The use of proprietary compounds has also resulted in an excessive number of compounds being specified in the LPS's, many being duplicates of each other. By using qualified products, the number of compounds needed can be reduced.

RECOMMENDATION

1) It is recommended that the practice of using unqualified solid film lubricants in naval rework be discontinued and that these compounds be replaced by products qualified under a military specification.

2) To aid in this transition it is recommended that a list be prepared which describes the solid film lubricants and categorizes them into logical groupings from which replacements and substitutions should be made.

3) The number of lubricant categories should be kept to the absolute minimum necessary to adequately cover the required applications.

Date: April 29, 1971
Recommendation No. 9
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Obtaining Solid Film Lubricants on Open Purchase

BACKGROUND

Most solid film lubricants have a shelf life of one (1) year or less. Present research and development efforts have been directed toward extending this life to two (2) years. However, in the meantime lubricants supplied through normal channels may have extensive delays both in the Vendors distribution system and in the Navy's supply system. As a result, solid lubricants can (particularly aerosols) arrive in the shop later than the shelf life date on the can.

RECOMMENDATION

It is recommended that solid lubricants be obtained on open purchase, directly from the vendor. The vendor should be required to certify that the products conform to military specification.

Date: April 29, 1971
Recommendation No. 10
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Training in Solid Film Lubrication Processing

BACKGROUND

Many discrepancies have been found in the processing of bonded solid lubricant films. For example, very little use of surface pretreatments have been found, cleaning procedures are inadequate, there is no thickness control, and short-cuts have been taken in film curing. This situation is understandable and is the natural consequence of efforts to reduce costs accompanied by a lack of information on the consequences of these actions. Poor films cause early part failures. Industry has found it necessary to "qualify" an operator. By this is meant that the sprayer is carefully instructed in the proper application of solid film lubricants and the results of his work are periodically checked by running wear tests on the parts he coated. Laboratories such as NADC use even more rigorous procedures. Some procedure of this nature should eventually be instituted at the NARFS. However, the most immediate need is for instruction and training in this area.

RECOMMENDATION

A training program should be developed in Solid Film Lubrication Processing. This should consist of the necessary audio visual aids (movie, booklet, etc.) but also a short course of instruction (3 to 4 days). Technically, it should be aimed at the shop foremen and the sprayer. The course should contain actual demonstrations of the processing with participation by the trainees. A retraining cycle should be included.

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 11
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Preparation of a Technical Manual on Bonded Solid Lubricant Film Application

BACKGROUND

Solid film lubrication is a very specialized field which has been developed in the last 20 years. During the past 10 years many new lubricants and processing techniques have evolved. It is not surprising therefore that much of this information has not been translated into practice at the NARFS. In the survey many discrepancies and poor practices have been found. These are as follows:

1) Out of date lubricants are generally used
2) Very little evidence of the use of surface pretreatments has been found
3) Cleaning procedures are inadequate
4) There is no thickness control in spraying the film
5) No quality control procedures are apparent
6) Paint spray equipment and techniques have replaced those recommended for solid film lubricants
7) Parts are handled without gloves
8) Parts are generally stored where they can be contaminated with dirt
9) Oil is often used in reassembly.

There is also much confusion about solid film lubrication which has resulted in many costly procedures being instituted and a large number of engineering hours being expended in looking for substitute films and procedures. The technical areas where information is needed by the NARFS are the following:

1) Corrosion with solid lubricants
2) Means of used film removal
3) Knowledge of the film composition and its effect

It is very important that the correct films and procedures be used. Solid lubricants are used in many critical applications (blades, fuel control valves, control surfaces). With incorrect procedures part lives can be shortened from millions of cycles to practically nothing. Clearly much more information on this subject is needed by technical personnel at the NARFS.

RECOMMENDATION

It is recommended that a technical manual on solid film lubrication be prepared. It should be similar in scope and purpose to the Aircraft Cleaning and Corrosion Manual (NAVAIR 01-1A-509) and the manual on "Maintenance of Aeronautical Antifriction Bearings (NAVWEPS 01-1A-503). The purpose of the manual would be to collect in an easily available source, practical information, on solid lubricants. At the present time no such publication exists in government or open literature. This manual should emphasize those areas where infor-

Recommendation No. 11 (Continued)

mation is most needed at the NARFS and should include the following recommendations:

a) Responsibility for solid film lubrication should be vested with the person responsible for lubricants.

b) Information should be collected and suggestions given for the removal of solid lubricant films.

c) A suggested LPS which contains only the necessary films should be prepared. It should contain the latest technology in auxiliary treatments.

d) A separate facility should be designated as the "Special Coating Facility." It should contain facilities for vapor degreasing, grit blasting, applying and curing solid film lubricants.

e) A "signed routing tag" system should be set up for solid lubricant parts. The tag should be prepared by the lubricant specialist and should contain the following:

1. Lubricant
2. Material
3. Stripping procedure
4. Inspection
5. Surface roughening
6. Vapor degrease
7. Chemical Surface Pretreatment
8. Wash and Dry
9. Cure (temperature and time)
10. Inspect
11. Part No. and Name

A space should be marked for the date, time, and initial of the operator. Tags should be saved for quality control purposes.

f) Part work forms should contain the name of the specific lubricant or military specification. The use of just the term "Dry film lubricant" should be avoided.

g) Where practical the parts which have received a bonded solid lubricant film should be sealed in a noncontaminating bag for shipment and storage. The part should be tagged with the instruction "bonded Solid Film Lubricant - Do Not Oil When Reassembling".

h) Two quality control procedures should be instigated on random parts: a tape adhesion test and a film thickness measurement.

i) All personnel handling solid film lubricated parts should wear clean cotton gloves.

The following are the recommended sections for the subject manuals:

1) Types of solid lubricants and properties
2) Types and composition of solid film lubricants
3) Pretreatments
4) Surface modification
5) Facilities for film applications
6) Application procedures

Recommendation No. 11 (Continued)

7) Handling and storage
8) Quality Control
9) Parts generally coated in naval aircraft
10) Expected performance of specific components
11) Effect of application and operational variables on performance
12) Causes of failure
13) Stripping
14) Corrosion effects

Date: April 29, 1971, Revised June 27, 1971
Recommendation No. 12
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Solid Film Lubrication for S2D and C1A Wing Lock Fittings

BACKGROUND

On both of these aircraft a male and a female part mesh at the wing fold. These parts act as the locating surface for the two wing portions. A pin is then inserted in a hole in the wing lock fittings to lock the wing in place. No lubricant is presently used on the surface of the fittings and damage results in service. On the C1A, the parts are made of 7075 aluminum and on the S2D and E, the parts are made from 4130 (for example, fitting P/N 121 WML-0063-5). There are about 30 male and 30 female fittings on an aircraft. On 30 April we were told by M. Spalding, controller of the wing shop at Quonset Point NARF that an estimated 25 to 35% of these fittings were damaged. These were buffed and ground to be put back in shape. Depending upon the amount of damage it takes up to 1 hour per fitting. Thus, one might estimate 15 to 20 hours of rework per aircraft.

RECOMMENDATION

A lubricant conforming to military specification, MIL-L-8937 is recommended for this application, and in service an aerosol spray of MIL-L-23398 for touch-up purposes. Surface pretreatments for the MIL-L-9937 are as follows:

(a) vapor degrease
(b) vapor blast with 120 mesh $Al_2O_3$ grit
(c) phosphate steel surfaces
(d) anodize aluminum surfaces

For new wing lock fittings a wear resistant treatment of plasma sprayed Al bronze or nickel may be necessary prior to application of the solid film lubricant.

Date: 6 May 1971, Revised June 27, 1971
Recommendation No. 13
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Wear of Landing Gear Brake Pistons and Cylinders

BACKGROUND

A general problem occurring in many Naval aircraft landing gear brake systems is excessive wear of the aluminum or magnesium brake cylinders and pistons. This wear leads to

a) excessive leakage
b) excessive parts usage and scrappage and
c) excessive rework labor hours

The brake cylinder is not usually a separate component, rather it is usually machined into the brake housing and a single brake may contain several cylinders, generally between three and eight.

The wear itself may differ in cause. In some systems it appears to be abrasion resulting from contaminant particles. In other systems it appears to be adhesive wear resulting from the rubbing of the piston and cylinder. In still others it appears to be a combination of the two. Some of the specific findings are as follows:

1. A4 Landing Gear Brake: Abrasion of Brake Housing and Brake Pistons - Dirt between the anodized aluminum brake piston (PN9523532; FSN IRM-1630-586-1368-DA) and housing (PN9560348) causes significant wear of the two. This requires replacement of many standard pistons, and when the condition is severe enough, which is often, the reboring and reworking of the housing to accept an oversize piston (PN9523975; FSN IRM-1630-717-1170-DA). The next step is to discard the whole brake and this is done about every second rework, at Pensacola. To give some idea of the magnitude of the problem, Alameda alone in the last 6 months replaced 62 standard size pistons and used 36 oversize pistons.

2. A3 Landing Gear Brake Housing: Adhesive Wear - The rubbing action of the brake piston against the cylinder wall of the housing (PN9532267; FSN IRM-1630-776-0740-BA), causes excessive wear. This is sometimes remedied by housing rework and substitution of oversize pistons (PN9531676), but housings ultimately have to be scrapped; Alameda, in the last six months purchased 2 housings.

3. S2A, C1A Landing Gear Brake: Wear of Piston and Housing - The brake piston consists of a large diameter anodized aluminum annular ring (PN148143), moving in an annular groove in the housing (PN15196). As in other brake systems, wear is an important problem. In the last 8 months, Alameda bought 30 pistons. It is not clearly understood whether the wear is of the adhesive type, resulting from the surface contact of the two parts, or of the abrasive type, arising from dirt (possibly contaminants in the hydraulic fluid).

4. H3 Rotor Brake: Caliper Housing Wear - Excessive wear of the anodized

Recommendation No. 13 (Continued)

aluminum caliper housing (PN9440345; FSN RH-1630-874-7274-OH7x) promotes corrosion and leads to significant rework with reboring to accept oversize pistons, and actual caliper discards. In the past 6 months, Quonset Point used 50 oversize pistons (PN CYR9420494; FSN RS-1630-633-632-6H6x) and 2 caliper housings.

5. H2 Rotor Brake: Caliper Housing Wear - Excessive wear of the anodized aluminum caliper housing is occurring in a manner identical to that on the H3 Rotor Brake. Considerable rework is occurring and Quonset Point has had to discard 3 caliper housings (PN9440998; FSN RH-1130-178-8534-BH7x) in the past 6 months as beyond rework.

6. A7 Landing Gear Brake: Wear of Pistons and Housing - The rubbing of the brake actuating piston (PN 9534473) in its cylinder (PN 9535849) causes wear and rejection of both in this multiple disc system; this was considered a major problem at Jacksonville.

7. E1B, S2B Brake Piston - Excessive wear is occurring on the brake actuator piston (PN 151092).

8. F8 Landing Gear Brake - This is an essentially caliper style brake system. Excessive wear of the magnesium actuating cylinder housing (PN 9540859) necessitates use of oversize pistons (PN 9522608) and later on sleeves and regular size pistons (PN 9522166), both of which also show wear.

9. A6 Landing Gear Brake - The actuating hydraulic system in this multiple disc system consists of eight pistons (PN 9524582) in cavities in a housing (PN 9525238). Due to wear in the cylinder region, pistons, the housing, or the whole assembly (PN 9560538) have to be discarded. This is a common occurrence at Norfolk.

In commercial non-naval rework hydraulic and sliding components are routinely coated with wear resistant materials. For example, Union Carbide Coating Service reworks the Boeing 707 and 727 tail stabilizer cylinder by plasma spraying it with aluminum bronze. They rework C-141 hydraulic cylinders by applying 12 mils of chrome oxide; these are proof tested to 3500 psi. Hohman Plating and Manufacturing chrome oxide coats non-aircraft hydraulic cylinders which withstand pressures of 35,000 psi. These organizations have also successfully used sprayed plasma nickel and tungsten carbide in non-aircraft applications.

RECOMMENDATIONS

A program is needed by NAVAIRSYSCOM to evaluate the possible means of controlling brake system piston-cylinder wear problems with a plan based on the use of actual hardware in order to provide a solution. This program should consider materials and processes.

It is estimated that possible candidate materials to be considered for application to the surface of these parts could include:

Recommendation No. 13 (Continued)

| | |
|---|---|
| Aluminum bronze | 400 Series stainless steel |
| Chrome oxide | Cobalt Alloys |
| Plasma nickel | PTFE filled hard anodize |
| Cemented tungsten carbide | Soft metal platings |
| Molybdenum | |

Some of the application processes which could be considered include:

Plasma Spraying
Wire Spraying
Plating
Anodizing

A survey should be made to determine which materials and processes are likely to give both adhesive wear and abrasive wear resistance. Candidates should also satisfy the requirement that they are implementable with the NARF's present equipment and facilities.

Actual brake hardware should be used in a test program to establish which of the materials and processes candidates, firstly, will actually work, and secondly, be simple to implement at NARFS. The results of this testing should be applicable to actual flight hardware.

Date: May 6, 1971
Recommendation No. 14
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Solid Film Lubricant Research and Development Gap

BACKGROUND

In the course of this program thirteen (13) formal recommendations have been made to date concerning current application technology and related aspects. This survey has also found a need for a redefined R & D effort which takes into account not only the operating environment but also the realities of production and facilities requirements and maintenance time. Solid film technology in terms of NARF conditions has led to materials development with several significant limitations. Several of the more important research gaps will now be cited:

1. Need for a Single Multi-Purpose Solid Film Lubricant Material - The NARFS have more than 100 different, proprietary, solid film lubricants available to them all with limited shelf life, together with differences in processing, cleaning, and curing. With far too many products available to choose from, and specified in manuals, a natural reduction in the number of films used has been occurring, with the result that films non-multi-purpose in abilities, have been improperly used in applications where they could only fail. The development of a true multi-purpose lubricant material in terms of extended wear life and corrosion protection capabilities is greatly needed.

2. Need for Solid Lubricant Materials Functional in the Presence of Greases, Oils, and Contaminants - Present solid lubricant films lose practically all effective wear life if rubbed in the presence of oils, greases, or dirt. Contamination of solid films by these contaminants is a very common occurrence in actual naval aircraft applications. These lubrication failures lead to considerable rework time and cost, much of which could be eliminated if solid films compatible with contaminants existed. Such materials should be developed. No technical barrier appears to exist to limit the development of new solid film lubricants stabile in the presence of such contaminants, and the development of such materials should be promoted for obvious reasons.

3. Need for a Solid Lubricant Material not Requiring Elaborate Surface Cleaning and Pretreatment Procedures - Present solid film lubricants require a many stepped sequence of surface cleaning and pretreatment, in order to obtain long wear life. This many stepped sequence of events is very inconvenient to production requirements, is prone to error, and together with curing time represents eighty (80) percent of the film processing time. Recent developments in the field of organic coatings have shown that outstanding adhesion combined with abrasion resistance can be achieved by essentially single step processing. On this basis it is considered that solid films can be readily perfected with simple processing procedures, and such development should be undertaken.

4. Need for Solid Lubricant Materials Not Sensitive to Applied Film Thickness - Present solid film lubricants exhibit optimum wear life only when applied over

Recommendation No. 14 (Continued)

a very narrow range of film thickness. Obtaining this film thickness range demands great skill and experience by the spray operator, and conflicts with the normal practice and requirements of NARF spray operations. In order to eliminate critical requirements for operator skill as well as a dependency on a narrow range of film thickness, development should be undertaken to provide films with excellent wear properties based on a large allowable film thickness range.

5. Need for Outstanding Corrosion Characteristics of Solid Film Lubricant Materials - Corrosion protection of metal surfaces by solid lubricants is a vital requirement. Current test procedures are based on essentially unworn solid films under static test conditions. However, in service, film disruption occurs instantly during start-up operations and continues during the service life of the part. There is a critical need for research techniques, which provide information on the corrosion protection of disrupted films. Further, little if any technology has been aimed at understanding the mechanism of corrosion protection by chemical addition agents for solid film lubricants. Based on this severe limitation, a study to understand the mechanism for corrosion inhibition in solid film lubricants especially under service conditions is recommended.

In view of the far reaching developments recommended above, further discussion and description will be provided if requested.

RECOMMENDATION

Based on the obvious technical and economic benefits to be derived, it is recommended that action to implement a program be taken as soon as possible concerning the above recommendations.

Date: May 11, 1971
Recommendation No. 15
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Placing Instructions for Use on Solid Lubricant Containers

BACKGROUND

An inspection of the application of solid lubricant films at the NARFS has shown that in many cases these films are incorrectly applied even though the LPS's describe accurately and in detail the correct process. Since the life of these films are very sensitive to the application variables such as pretreatments, surface roughening, cleanliness, thickness, drying and curing, further emphasis on correct processing is needed. The longer wear lives obtained may make it possibde to eliminate recoating at rework. Since a large number of people do spraying at any one facility it is important to get the instructions directly to them.

RECOMMENDATION

It is recommended that instructions for the application of any dry film lubricant be placed on the container by the manufacturer. The container should also carry the warning of reduced life if applied differently.

Date: June 3, 1971
Recommendation No. 16
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: P3A Wing Flap Actuator SPL 5568-3

BACKGROUND

This ball jack screw contains several severe wear areas. The thrust rolling contact bearing is being replace 80% because of fretting of the balls in the races. The manual calls for the parts to be phosphated (MIL-P-16232) and lubricated with MIL-G-23827. Although this part could be the subject of a detailed study (materials, design, etc.) because of its wear behavior an improved lubricant can be suggested which may reduce the fretting wear of the thrust bearing.

RECOMMENDATION

Based upon superior anti-fretting properties exhibited by MIL-G-81322 greases in several different aircraft applications, it is recommended that it be substituted for MIL-G-23827 in the subject application.

Date: 14 June 1971, Revised June 27, 1971
Recommendation No. 17
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Rework of Scratched Chrome Plated Hydraulic Pistons

BACKGROUND

Abrasive contaminants often cause deep scratches or pits in the chromium plating of hydraulic pistons. These parts are usually reworked by stripping the plating, replating, and finishing — a time consuming and expensive process. Mildred Patterson at Alameda NARF has developed a simple alternative, for use when the damaged area occupies no more than about 10% of the total surface area, which is currently being used by the Air Force, but remains unused in many NARFS. The process consists of brush plating a nickel strike on the surface followed by a nickel-copper fill and a nickel-cobalt or nickel-tungsten cap. At Robbins AFB, use of this brush plating approach has reduced the rework time on the chrome plating of the C-141 main landing gear piston from three (3) weeks to four (4) hours. Inspection of those reworked parts after extensive service has shown no greater damage propensity on the brush plated areas than on the remaining original chrome plated area.

RECOMMENDATION

It is recommended that the rework of chrome plated hydraulic pistons, due to deep scratches in the chrome, where the damaged area occupies no more than approximately 10% of the total chrome plated surface area, be done using the above described Alameda brush plating technique.

Date: 14 June 1971
Recommendation No. 18
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Improved Shot Peening of Compressor Blade Roots

BACKGROUND

The blade roots of virtually all types of jet engine compressor blades are presently shot peened, at the NARFS, to improve thier fatigue lives. A recently developed improvement in shot peening offers a simple and inexpensive way to significantly improve the effectiveness of the process. Proprietary research at MTI has shown that the conventional shot peening process, in addition to cold working a surface and thereby inhibiting the propagation of fatigue cracks, also puts micro-damage into the cold worked surface which in turn serves as sources of fatigue initiation. This secondary effect is of smaller magnitude than the inhibition of crack propagation effect, so the overall effect is a significant improvement in fatigue life. However, if the surfaces to be peened are coated with SAE 40 mineral oil, the presence of the oil allows the cold working to occur unhindered while preventing the occurrence of secondary damage. Actual tests have shown that simply brushing the surfaces with SAE 40 mineral oil so they are dripping wet, at the time of peening, will <u>increase</u> fatigue life by 20%.

The utilization of this improvement by the NARFS would be simple to implement. The operator who loads the blades into the shot peening machine would also be required to brush them with oil before turning on the shot-blast.

RECOMMENDATION

The NARFS coat the blade roots of all jet engine compressor blades with SAE 40 mineral oil, at the time of shot peening during rework, in order to achieve an improvement in blade fatigue life.

Date: 14 June 1971
Recommendation No. 19
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Fastener Corrosion

BACKGROUND

Alameda has observed a corrosion problem which they attribute to solid film lubricants on fasteners. Graphite was used in some of the applied films and research has indicated that graphite so used can cause corrosion. However, others have not observed this corrosion problem. Inspection of the literature indicates that corrosion has always been a problem with or without solid film lubricants. Since Alameda is now removing solid film lubricants from fasteners and other NARFS have become concerned about this problem but are not removing solid film lubricants from fasteners, some definite conclusions are required. Before this can be done, certain questions must be answered.

RECOMMENDATION

It is recommended that a survey be conducted to answer the following questions:

1. Is this a general problem or only a local incident?

   An inspection should be made of the wing fasteners in the A3 and another aircraft which has similar usage as they arrive for rework to determine the frequency of fastener corrosion and if this corrosion can be attributed to solid film lubricants.

2. Are Solid Lubricants being correctly processed?

   If there is corrosion and it can be attributed to solid lubricants, then a survey should be conducted to determine if the correct processing of solid lubricants is being carried out. The corrosion may be due to the solid lubricant or incorrect processing. To conduct this survey, visits should be made to manufacturers of the fasteners, the vendors, and to the aircraft manufacturers.

3. Are solid lubricants really necessary on fasteners?

   Originally fasteners were supplied with cetyl alcohol and at the present time most are still supplied this way. They must be ordered specially to obtain them with solid lubricants. The question thus arises if solid lubricants are necessary, if not, fasteners can be used without them. To answer this question a literature search should be conducted since it is known that fastener fretting studies have been conducted at Boeing, NADC, WADC, and possibly other laboratories.

4. Experimental study of fastener corrosion.

   If solid film lubricants offer major advantages then an experimental

Recommendation No. 19 (Continued)

program should be conducted to determine the most suitable corrosion resistant film to be used on fasteners. A simple riveted sample can be vibrated in a salt spray cabinet with the following variables:

a. Lubricant
b. Clearance
c. Rivet stress
d. Protection coating

The vibration and the salt spray should simulate actual service conditions.

Date: 14 June 1971
Recommendation No. 20
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Quality Assurance for Solid Film Lubricated Parts

BACKGROUND

A survey of the application of solid film lubricants in the Naval Aircraft Rework Facilities has indicated that there are many unsatisfactory practices which can result in short film life and early part failure. The results of poor film processing is usually manifested in either excessive film thickness or poor film adhesion. Quality assurance programs on a sample basis is a relatively simple matter.

RECOMMENDATION

It is recommended that a quality assurance program be instituted on representative sample parts coated with solid film lubricants at the Naval Aircraft Rework Facilities. Two tests are recommended: a film adhesion and film thickness. These tests should conform to the tests outlined in paragraphs 4.7.2 and 4.7.3 of Military Specification MIL-L-8937A (AS6) with the exception that actual test parts should replace the aluminum test panels.

Date: 14 June 1971
Recommendation No. 21
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Seals

BACKGROUND

Leakage resulting from poor seal performance appears to be a major general problem in the operation of naval aircraft, and necessitates spending considerable rework time. The reasons for these seal failures include improper original seal design, improper materials selection, and faulty seal installation. Three typical examples:

1. F8 landing gear actuating piston O-ring seal.
2. F4J main landing gear hydraulic cylinder rubber piston ring.
3. SH3-D servo cylinder in rotor head, excessive seal wear.
4. F4 starter seal (carbon graphite).

Although many seals are replaced during aircraft rework, the replacement seals are usually made of the same materials and are of the same design as the original seals. None of the developments of recent years in improved seal materials, design, or installation techniques are utilized in seal replacement.

RECOMMENDATION

A study should be undertaken on the application of improved seal technology to naval airframes. This study should include the following tasks:

1. An examination of the latest current developments in seal technology for the purpose of finding things utilizable in naval aircraft rework.

2. An analysis of the specific seal problems existing on naval aircraft, and the state of their art.

3. The making of specific recommendations as possible areas of improvement are revealed by the program.

Date: 14 June 1971
Recommendation No. 22
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Standard Cure for Bonded Solid Film Lubricants

BACKGROUND

At the present time there are approximately 130 solid film lubricants which have cures ranging from 150 F to 1000 F and cure times ranging from 24 hours to 1 minute. In some cases the different cures are necessary but in many cases they are not. Furthermore, it is unrealistic to think that shop personnel will tie up a large furnace for 2 hours at 300 F for one part when he has 50 other parts waiting which have a 375 F cure for one hour. Almost anyone could cure them all together at 350 F for 1-1/2 hours. Since the cures are not critical, some consolidation can be made. In fact this is, to a large extent, currently being done by shop personnel at the NARFS.

RECOMMENDATION

It is recommended that an investigation be made of the qualified products of solid film lubricant and the products now being used at the NARFS to determine insofar as possible if a single cure can be recommended.

Date: June 14, 1971
Recommendation No. 23
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT:. Wear Technology

BACKGROUND

The wear of mechanical components is a common cause of rework, and parts scrappage. A few illustrative examples:

1. F8 main landing gear cylinder barrel (PN 615 7A11C, 601401-1LH, 601401-2RH). Due to the increase in the I.D., resulting from wear of this aluminum surface, 75% of these parts are scrapped at rework.

2. P3A hydraulic dual brake valve lever (PN 15929). Excessive wear on the mating steel surfaces of the steel roller and pin; 60% replacement at rework.

3. A6 flapper on cylinder assembly (PN 19614); 75% parts replacement due to wear.

Significant advances have been made in wear technology in recent years. Materials, treatments and methods have been developed which allow the salvage of many parts presently being discarded. They could also increase the operating interval of parts presently being reworked.

RECOMMENDATION

A study should be undertaken on the application of advanced wear technology to mechanical components for naval airframes. The study should include the following tasks:

1. An examination of the latest developments in wear technology, including materials, processes and methods, in order to pinpoint the latest readily available technology applicable to naval aircraft.

2. Visits to Naval Air Rework Facilities to determine the actual wear problems found on naval aircraft, and current methods and processes.

3. The making of specific recommendations on possible areas of improvement as revealed by the program.

Date: June 14, 1971
Recommendation No. 24
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: A6 Landing Gear Brake: Excessive Disc Usage

BACKGROUND

Bonded solid lubricant films are not used on critical dry sliding surfaces with the following consequences:

1. Rotating discs (PN 9532757) show excessive spline wear, and are scrapped when they fail to meet the limits of a go and no-go gage.

2. Stationary discs (PN 9532756) show excessive spline wear.

RECOMMENDATION

On A-6 landing gear brake, the spline sliding surfaces of the rotating disc (PN-9532757) and stationary disc (PN 9532756) should be lubricated with extreme environment solid film lubricant MIL-L-81329A.

The following surface pretreatments should be used in the parts processing:

1. Vapor degrease with trichloroethylene.
2. Vapor blast - 120 mesh alumina.
3. Phosphate as specified by Type M, Class 3 of MIL-P-16232.

Date: June 14, 1971
Recommendation No. 25
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: F4J and F4B Landing Gear Brake: Excessive Disc and Spider Usage

BACKGROUND

Bonded solid lubricant films are not used on critical dry sliding surfaces with the following consequences:

1. Rotating discs (for F4B, PN AP 313590; for F4J, PN AP 320545) are short lived due to excessive spline wear; dimensional tolerances are not met.

2. Stationary discs (for F4B, PN AP 313591; for F4J, PN AP 320546) have excessive spline wear and warpage partially induced by spline friction caused friction moment.

3. Spider assembly (for F4B, PN AS 216339; for F4J, PN AP 320561) excessive wear on spider spline surfaces.

RECOMMENDATION

On F4J and F4B spline sliding surfaces, coat these surfaces with extreme environment solid film lubricant MIL-L-81329A:

1. Rotating disc (for F4B, PN AP 313590; for F4J, PN 320545)
2. Stationary disc (for F4B, PN AP 313591; for F4J, PN AP 320546)
3. Spider assembly (for F4B, PN AS 216339; for F4J, PN AP 320561)

The following pretreatments should be used:

1. Vapor degrease with trichloroethylene
2. Vapor blast - 120 mesh alumina
3. Phosphate as specified by Type M, Class 3 of MIL-P-16232.

Date: June 14, 1971
Recommendation No. 26
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: A6 Landing Gear Brake Assembly

BACKGROUND

The A6 brake assembly (PN 9560538) is actuated by eight (8) pistons (PN 9524582) moving in an end plate (PN 9525238). The movement of the pistons wears out this expensive forging, which is then scrapped.

RECOMMENDATION

A6 landing gear brake actuating hydraulic cylinder bores (PN 9525238) should be rebuilt by either sleeving or brush plating. The Alameda NARF developed nickel-tungsten-cobalt brush plate may be suitable.

Date: June 14, 1971
Recommendation No. 27
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: A6 Electrohydraulic Rudder Servo Power Pack End Cap

## BACKGROUND

A steel shaft rubs on the aluminum surface of the end cap (PN 19899) causing galling. Norfolk has found that 95% of the parts of rework show this damage. The problem arises because very little lubricant gets past the sealing rings to boundary lubricate this surface. Matters are worsened by the possible presence of abrasive contamination.

## RECOMMENDATION

The salvage of the A6 electrohydraulic rudder servo power pack end cap (PN 19899) can be accomplished and the operating interval increased by plasma spraying the worn aluminum surface with 90-10 tin bronze or 410 stainless steel and then refinishing.

Date: June 28, 1971
Recommendation No. 28
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Hydraulic Control Valves

## BACKGROUND

Hydraulic control valves are checked against leakage specifications of so many drops per minute. With time, wear occurs, increasing the valve leakage to an unacceptable level, at which time the parts are presently discarded. Two typical examples are the F8U dive brake selector valve slide and sleeve assembly (PN 15424) and the P3A power brake valve slide and sleeve assembly (PN 18066; FSN RM-1630-821-468Y120). A publication by L.C. Horwedel ("Solid Lubricants as Organic Finishes," 47th Annual Technical Proceedings of the American Electroplaters Society, 1960) discussed work which has shown that solid film coatings can be used on the surfaces of this type of component for salvage purposes. In tests actual valves were coated and lapped to 3 rms finish and with no measurable leakage. This seems like a good way to reclaim components which are presently scrapped, and may in fact give better performance than new valves.

The solid film which was tested by Electrofilm (Electrofilm 4523) contained low melting point metal powders, which serve to reduce the film porosity by melting at cure. The film was under virtually no load in this application, and served more as a sealant than as a lubricant.

## RECOMMENDATION

Hydraulic control valve slides rejected for excessive leakage should be salvaged by coating the rubbing surfaces with a bonded solid film lubricant containing low melting point metal powders and then relapping to fit. Tests should be run on actual control valves, rejected because of excessive leakage, to find which commercial products are adequate and of these products, which one is best. Electrofilm 4253 should be included in this testing. It is recommended that Alameda NARF conduct the testing, but it should be noted that each NARF would benefit from the solution of this problem.

Date: June 28, 1971
Recommendation No. 29
Contract No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Designation of Wear Prevention Control Team

BACKGROUND

Unlike corrosion or fatigue, wear has become accepted as a natural consequence of motion. Because of this, many wear problems pass unnoticed or are "solved" by expensive methods such as frequent lubrication or high part replacement. A quick recognition of the difference between normal wear and excessive wear can save not only replacement costs of parts, but unnecessary utilization of engineering manhours. In the present survey many examples have been found where improvements in lubrication, materials, or design could be immediately suggested. For example, substitution of improved materials and processes in the rework of hydraulic cylinders, introduction of composite materials in critical wear areas, replacement of steel and stainless steel bushings, removal of graphite greases from landing gear applications, substitution of improved fretting lubricants in rolling contacts, application of solid lubricant to hinge pins, identification of corrosion prone solid lubricants, application of a tubing bending lubricant and many others.

These problems are often neglected or delayed in solution because specialists in this field do not exist at the Navy sites. It is felt that many hours could be saved and substantial cost savings could be realized by instant recognition and response to critical wear problems. A wear prevention and control team could offer a quick response to these situations.

RECOMMENDATION

It is recommended that NAVAIR establish a program which would encompass a wear prevention and control team whose responsibility it will be to seek out and correct high wear situations and to provide rapid response to critical failure situations. This team should maintain liaison between the NARFS and the advanced product groups of material suppliers, component manufacturers and air frame builders to insure that the latest readily available technology is used in the rework and overhaul of aircraft and is also made known to sourves of Navy new buys.

This team should consist of specialists in the following areas: lubricants, wear, component materials, and component design. It should also have one member from a Naval Rework Facility who is familiar with the practicalities of naval rework.

The following people have the required backgrounds and have demonstrated that they can work effectively together:

| | | |
|---|---|---|
| Wear | - | Dr. Eugene Finkin |
| Component Materials | - | Marshall Peterson |
| Lubricants | - | Leon Stallings |
| Component Design | - | Leo Winn |
| NARF | - | Robert Zilligen |

Date: June 27, 1971
Recommendation No. 30
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Salvage and Wear Prevention of Hydraulic Pistons and Cylinders

BACKGROUND

The general hydraulic cylinder wear and surface damage problem is similar to that of the hydraulic actuation systems of landing gear brakes (see Recommendation 13), only broader in scope as the general components come with a wider variety of materials and can have large length to diameter ratios. The operating interval and reliability of these components are limited by the inherent damage propensity of current materials. This is leading to large rework and replacement losts.

In commercial non-naval rework hydraulic and sliding components are routinely coated with wear resistant materials. For example, Union Carbide Coating Service reworks the Boeing 707 and 727 tail stabilizer cylinder by plasma spraying it with aluminum bronze. They rework C-141 hydraulic cylinders by applying chrome oxide; these are proof tested to 3500 psi. Hohman Plating and Manufacturing chrome oxide coats non-aircraft hydraulic cylinders which withstand pressures of 35,000 psi. These organizations have also successfully used sprayed plasma nickel and tungsten carbide in non-aircraft applications.

RECOMMENDATION

A program is needed by NAVAIRSYSCOM to examine and assess possible materials and processing approaches, for salvage and wear prevention purposes, for hydraulic pistons and cylinders.

This program should examine commercial rework practices, and review recent advances in wear resistant materials technology, towards possible applicability to Naval Air Rework Facilities.

Discussions should be held with both hydraulic component manufacturers and airframe builders, to properly assess possible limitations and constraints on possible new technology utilization.

It is estimated that possible candidate materials to be considered for application to the surface of these parts could include:

- Aluminum bronze
- Chrome oxide
- Plasma nickel
- Cemented tungsten carbide
- Molybdenum
- 400 Series stainless steel
- Cobalt Alloys
- PTFE filled hard anodize
- Soft metal platings

Recommendation No. 30 (Continued)

Some of the application processes which could be considered include:

- Plasma Spraying
- Wire Spraying
- Plating
- Brush Plating
- Anodizing

Date: June 27, 1971
Recommendation No. 31
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Hinge Bearings

BACKGROUND

Hinge bearings require frequent lubrication. For example, the maintenance card for the A-6 isolates 44 areas needing lubrication every 7 days. This leads to unreasonable demands on field personnel, which often results in neglect of these points, and ultimately substantial rework.

The F8J droop hinge consists of a long aluminum hinge with a steel pin. Cracking of the hinge resulting from inadequate lubrication is resulting in substantial rework.

The F4J has a similar problem (PN 32-11040-39, 40; PN 32-15549).

This seems like an ideal application for a solid film lubricant.

RECOMMENDATION

The hinge pins on piano type hinges on the F8J, F4J, A6, and other aircraft should be coated with a corrosion resistant bonded solid film lubricant, such as MIL-L-46010(A).

Date: June 27, 1971
Recommendation No. 32
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Control Surface Tracks

BACKGROUND

On many aircraft the flaps and slats are mounted on tracks. When the flaps move, the tracks are guided by steel rollers. The tracks are usually steel but may be aluminum. In service the rollers "freeze up" due to dirt, corrosion, or lack of lubrication. The tracks then slide instead of roll and are worn excessively. Some examples where this has been found are the following. On the A-3, it is estimated that about 50% were frozen. This problem has been treated by installing a grease fitting in the roller. Worn tracks are nickel plated to size and no lubricant is applied.

On the T-39 the flap tracks wear due to the seizing of the rollers. The problem is complicated by the fact that the tracks are no longer available and must be remade or repaired.

RECOMMENDATION

It is recommended that a corrosion resistant solid film lubricant be applied to control surface tracks; say, MIL-L-46010(A).

Date: June 27, 1971
Recommendation No. 33
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Institution of Dynamic Corrosion Test for Solid Film Lubricants

BACKGROUND

The corrosion resistance of solid film lubricants is presently determined by static methods on unworn specimens (i.e, specimens are put into a salt spray cabinet). The results of these tests do not entirely correlate with experience. Sliding causes film damage and compaction, both of which must influence corrosion protection. Parts in service are exposed to corrosive conditions while they are operating, or after they have operated and examples have been found of corrosion occurring on supposedly corrosion resistant films.

RECOMMENDATION

A dynamic corrosion resistance test should be instituted for measuring the corrosion resistance of bonded solid film lubricants. The test should consist of specimens sliding in a wear test apparatus operating in a corrosion promoting environment.

Date: June 27, 1971
Recommendation No. 34
Contr. No. N62269-71-C-0177
Air Task WR-1-0560

SUBJECT: Removal of Graphite Greases from Brake Manuals

BACKGROUND

Graphite is well known to promote corrosion. Efforts have been made to remove graphite containing compounds from airframe use and to substitute non-graphite containing compounds in their place. Aircraft landing gear brake manuals often call out the use of MIL-T-5544 which is a thread compound consisting of 50% graphite in petrolatum. This could be the cause of corrosion problems.

RECOMMENDATION

Aircraft landing gear brake manuals should no longer specify graphite containing greases, such as MIL-T-5544.